THE ATLAS BEAM VACUUM SYSTEM

R.Veness, CERN, Geneva, Switzerland

Abstract

The Large Hadron Collider (LHC) has recently started-up at CERN. It will provide colliding beams to four experiments installed in large underground caverns. A specially designed and constructed sector of the LHC beam vacuum system transports the beams though each of these collision regions, forming a primary interface between machine and experiment.

ATLAS [1] is the largest of the four LHC colliding beam experiments, being some 40 m long and 22 m in diameter. Physics performance, geometry and access imposed a large number of constraints on the design of the beam vacuum system.

This paper describes the geometry and layout of the ATLAS beam vacuum system. Specific technologies developed for ATLAS, and for the alignment and installation of the vacuum chambers are described as well as the issues related to the physical interfaces with the experiment.

INTRODUCTION

The vacuum system that passes through the ATLAS experiment is an integral part of the LHC beam vacuum ring, so must fulfil the machine requirements such as ultra-high vacuum (UHV), low electrical impedance and reliability. At the same time it is traversed by every particle that will be detected by ALTAS, so all material: chambers; supports; vacuum equipment, must be minimized.

In addition to this, access for installation and commissioning is challenging. The beam height is 11 m from the cavern floor and access between detectors limited. These aspects are covered in [2].

The design also takes into account operation at nominal LHC luminosity, where irradiation by particles from the interactions in the range of 10^5 Gy/year will limit both choice of materials and access times for personnel [3].

LAYOUT OF THE SYSTEM

Sputtered non-evaporable getter (NEG) films, developed at CERN during the 1990's [4] allowed a major change in UHV chamber design for ATLAS compared with designs for the LEP experiments. A few µm of NEG deposited on the inside of all the chambers give a very high distributed pumping speed for most desorbed gases. This removed the need for large pumps inside the experiment, and allowed chamber diameters to be reduced to limits imposed by beam aperture and mechanical stability. The only drawback is that they require activation by annual heating of the entire system to 180°C.

The ATLAS beam vacuum system consists of seven beam-pipes of 38 m total length, spanning the distance between the two TAS absorbers located at each end of the cavern. They are bolted together with flanges to form an ultra-high vacuum system, which can be fully baked-out *in situ*. The central chamber, called 'vacuum inner detector' (VI), is centred around the interaction point. It has an inner diameter of 58mm and is constructed of beryllium metal (see 'new technologies'). The remaining six chambers are installed symmetrically on both sides of the interaction point and named after the detector which supports them: VA (vacuum argon end-cap), VT (vacuum toroid end-cap) and VJ (vacuum forward shielding). They are constructed of thin-walled stainless steel tubes with diameters increasing progressively from 60mm to 80mm and finally to 120mm. These diameters are a compromise between allowing the detectors to approach the beam axis and maximizing the diameter to reduce interactions between the beampipe and particles from interactions.

Chambers inside different detectors are mechanically decoupled by vacuum bellows, which also serve to absorb thermal expansion during bake-out.

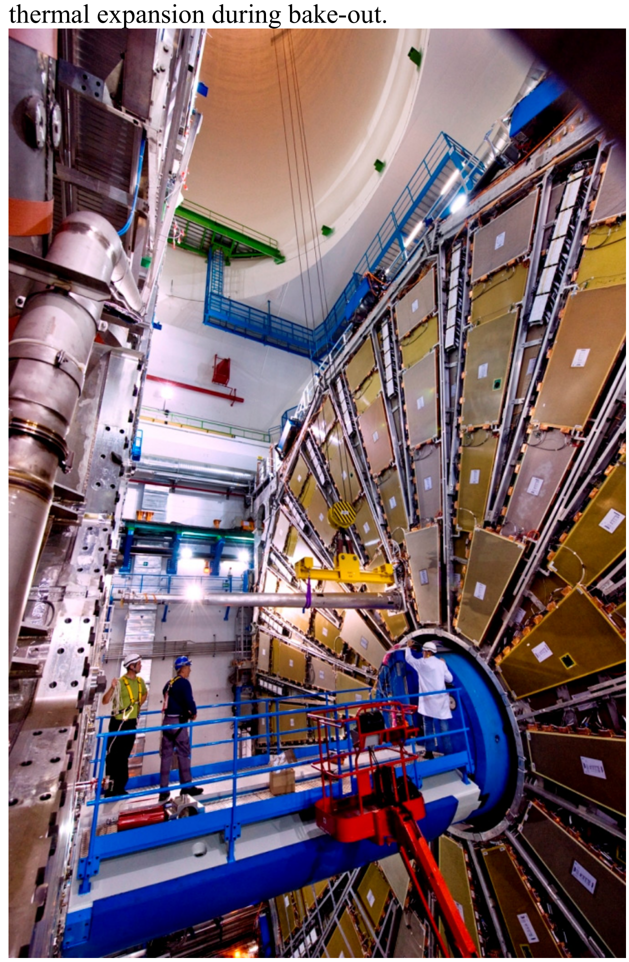

Figure 1: The final VJ chamber being lowered for connection to the TAS absorber.

NEW TECHNOLOGIES

Beryllium Chamber

Beryllium is the material of choice for beam vacuum chambers around collision points in particle colliders due to a combination of transparency to particles, high specific stiffness and compatibility with ultra-high vacuum.

A new generation of beryllium chamber technology was developed for the LHC experiments, using new manufacturing techniques to improve reliability and tolerances. Sections of 1 m in length were produced by gun-drilling and then machining beryllium blocks into tubes of 0.8 mm thickness. These tubes were then assembled by electron beam welding to produce the 7 m long ATLAS beryllium section. At each end, the beryllium was electron beam welded to short tubes and optimized UHV flanges made from AA2219 aluminium. This allowed the beryllium to be bolted to the adjacent chambers without special precautions. AA2219 was used for a combination of weldability and resistance to NEG activation temperatures, whilst maintaining an acceptable transparency.

Permanently Installed Bakeout Equipment

The design of the ATLAS detector means that access to the vacuum chambers is extremely difficult, particularly in the central region, where the PIXEL detector was assembled on to the beampipe on the surface and installed as a package. As use of the NEG coatings implies activation of the completed vacuum sector by baking (heating) the system to 180° C or more, it was decided to permanently integrate the bakeout system with the chambers. This system, consisting of heaters, insulation and temperature control was designed for ATLAS with the requirements of mass and envelope minimization, limitation of the heat load into the surrounding detectors, and radiation resistance to 5 MGy. Heaters are etched stainless steel foil, laminated between self-curing Kapton sheets at high pressure to avoid the use of adhesives. Thermal insulation on chambers is silica aerogel matting. The system is assembled on to the chambers by wrapping the heaters and insulation with self-curing Kapton tape, then with a thermo-retractable polymer tape. The chamber is heated to 150°C using the heaters which cures the Kapton, whilst being compressed by the thermo-retractable tape. Thermocouples with Kapton insulated cables are integrated with the heaters for control. A 50 μm aluminium foil is attached to the outside to serve as a reflector and electro-magnetic shield. Spacers made from graphite reinforced polyimide are integrated into the insulation to hold beampipe support collars (see figure 2).

Systems assembled for ATLAS were tested to function after 5 MGy of γ radiation, requiring ~200 W/m to maintain the chamber at 250°C in a simulated detector environment at -20°C.

The bakeout system, consisting of 90 heaters was fully cabled in-situ to racks on the cavern floor. This allows NEG activation to be performed with the detector fully closed, and from an environment safe from radiation.

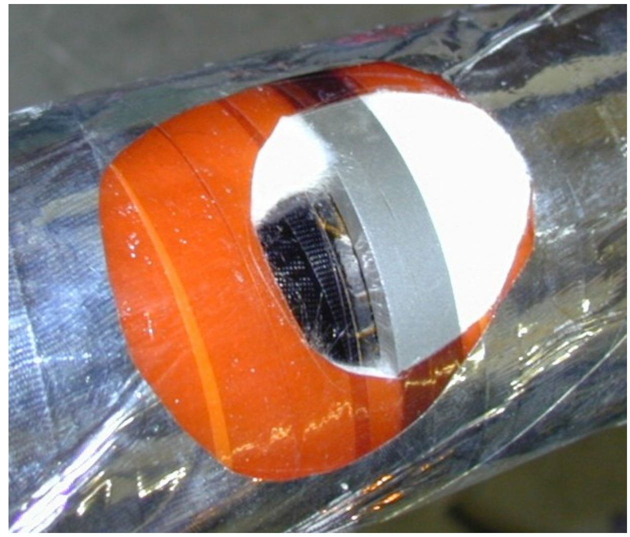

Figure 2: Cut-away sample of bakeout equipment showing heaters, insulation and spacer.

Minimised Ion Pumps

NEG coatings do not pump methane or chemically inert gasses, which are small but significant sources of outgassing in UHV accelerators. In order to keep beam-gas interactions to acceptable levels, some pumping speed for these gasses is required within the experiment. To provide this, a small, annular ion pump was developed in collaboration with Varian Spa. Ion pumping cells are distributed around the beam axis on the VA chamber, powered by a 6kV supply. The magnetic field for the pump is provided by the fringe field from the ATLAS barrel solenoid magnet. Figure 3 shows the open pump.

Figure 3: Minimised ion pump (open) mounted on a flange with minimised UHV flange (far end) and 63 mm conflat flange (near end).

Minimised UHV Flanges

Bakeable UHV flanges were designed for the VI and VA chambers. By using elastic metallic (Helicoflex) seals, high-strength AA2219 aluminium and careful design optimisation by finite element, the volume of the flange was reduced by a factor of 3 compared with a standard UHV flange, and the mass by a factor 8.8. Figure 3 shows standard and minimised UHV flanges on the ion pump chamber.

Remotely Actuated Flanges

Activation of the vacuum system will be highest at the interface between JV and the TAS absorber (see figure 1). To minimise interventions close to the beam axis by personnel, the VJ chamber is designed to be removed directly by crane from the surface. A fully-bakeable UHV flange system has been designed for this interface that can be opened and closed by rotating a handle from outside the shielding. A linear bearing system guides the chamber assembly in and out of position.

SUPPORTS AND ALIGNMENT

The supporting system is conceived to allow ATLAS to rapidly open for access to detectors without the need to open the beam vacuum to air and hence re-activate the NEG. In addition, operation at high luminosity will activate both beampipe and detector, so access times for personnel will be limited. Supports are designed to be both lightweight and rapidly removable, and then replaced in their same positions without re-alignment. The forward chamber supports can be re-configured to cantilever 10 m of beampipe from the cavern shielding structure, allowing the detectors to slide open over the chambers.

Alignment of the VI Beryllium Chamber

Alignment of the VI beryllium chamber is most critical in terms of machine aperture and detector performance. However, when installed as a package with the PIXEL detector and supported at 4 points along its length, there is no access to survey the central supports. The solution adopted was to measure the angular deformation of the chamber end flanges as an indicator of the chamber straightness. The deformation of the chamber with it's 4 supports was characterized before installation using a laser mounted on one end flange and a CCD camera on the other. When installed, this information can be used to re-position the central two supports relative to the ends. A data acquisition system in LabView gives a graphical representation of the chamber misalignment, allowing supports to be adjusted. Laser and camera are mounted on leak-tight flanges so that the NEG coated chamber can be maintained in a clean environment during alignment. Chamber straightness in the order of 0.5 mm was achieved using this method.

CURRENT SITUATION AND FUTURE PERSPECTIVES

The ATLAS vacuum system was fully installed and commissioned during 2007-8 and received beam for the first time in September 2008. Static pressures were typically in the range 10^{-11} mbar.

A number of upgrades are planned. The forward (VA and VT chambers) were produced from stainless steel. Simulations have since shown [3] that a 30% reduction in background in the ATLAS muon detection system would be achieved by replacing these with aluminium. In addition, such a change would reduce activation and hence facilitate personnel access.

ATLAS also plans to add an additional layer of PIXEL detector between the VI beryllium beampipe and existing detector. The required space could be gained by replacing the existing beryllium beampipe with one of smaller diameter and supporting the new detector and services from it.

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