EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

CERN - TS Department

EDMS Nr: 473745
Group reference: TS-MME

TS-Note-2004-033
5 May 2004

SPECIAL COATINGS FOR THE LHC

S. Calatroni

Abstract

Several LHC components require a thin film coating. These coatings fall in two main categories, namely NEG coatings to improve the vacuum behaviour of chambers or conductive coatings to decrease the surface impedance of components. Examples of the first category are the intersection vacuum chambers of the different experiments, where the required vacuum can be obtained only with a NEG coating because of the large distance of the nearest pumping station. The graphite jaws of collimators are an example of the second category. In this case the high impedance of graphite must be decreased by a thin copper coating. These and other cases will be illustrated both with respect to the machine requirements and to the production programme.

Presented at the TS Workshop
Archamps, France, May 4 – May 6, 2004

1 INTRODUCTION

Thin (or thick) film coatings are applied in industrial practice and in the LHC in particular whenever there is a technical or economical advantage over bulk materials, or when a bulk material satisfying all the required properties does not exist. Several technologies exist for the deposition of thin films. In this paper the attention will be concentrated on films produced by vacuum deposition technologies (mainly sputtering).

In the case of the LHC machine there are several cases where the use of films is necessary, the most important in terms of number of pieces or of technical impact being the coatings for the RF cavities and RF components, the NEG coatings of almost all the warm vacuum chambers and the coatings aimed at reducing the local impedance of the machine components. The LHC experiments also integrate a large number of components where thin film coatings are a key element (e.g. photocatodes, mirrors) but these will not be discussed here.

2 COATINGS FOR RF COMPONENTS

Among the first components ever to be manufactured for the LHC were the 16 superconducting RF cavities (plus 4 spares), made by sputtering a 1.5 µm thick niobium layer onto a copper substrate. These were industrially produced by one of the three companies that manufactured the cavities for the LEP collider with an identical technology, and for which the challenges had been mostly solved during the phase of LEP production [1]. The former EST/SM group (now integrated into the TS/MME group) was in charge of setting-up the coating parameters for the new geometry and producing a couple of prototypes (Fig. 1).

The coating of the components for the RF main couplers is instead still ongoing. The most crucial components are the Al_2O_3 cylindrical ceramic windows that separate the machine vacuum from the waveguides, and which must withstand with negligible losses a transmitted power in excess of 150 kW. In order to avoid arcing at the vacuum side the ceramic is coated with a thin highly resistive titanium layer, which reduces the secondary electron emission and prevents accumulation of electrical charges while maintaining a negligible RF dissipation. In order to finely tune the resistance of the layer to obtain the required 10 MΩ value, in-situ measurement during coating is mandatory. For this reason thicker coatings having a resistance of the order of several kΩ are made on the outer rim of the ceramics to ensure a reliable electrical contact between the final inner layer and the external brazed collars (Fig. 2). A double check of the quality of the resistive coating is provided by monitoring during the process the hydrogen partial pressure, which has a well characterised behaviour in the coating configuration employed. The required resistance is typically obtained two minutes after the hydrogen pressure has attained a well identified condition.

The extension coaxial tubes that connect the warm part of the power coupler to the cold cryostat, which are made of stainless steel in order to minimize the heat losses are also coated on their inner surface with a high-quality copper film aimed at reducing the RF losses to an acceptable level. Also in this case the technology developed for the LEP coupler extensions has been extended in a straightforward way.

3 COATINGS FOR EXPERIMENTAL VACUUM CHAMBERS

To achieve a vacuum in the LHC experiments that allows maintaining the background interaction rate at an acceptable level, it is mandatory to apply a NEG coating on a large part of the experimental chambers [2]. The total length of the vacuum chambers housed inside the detectors is of the order of several tens of meters for all the four major LHC experiments, and are composed of smaller sections that can however be as long as eight meters (Fig. 3). The vacuum chambers inside the detector have an overall slightly conical shape, which results from the competing needs of having a high conductance towards the pumping stations located at the extremities, and a reduced diameter at the interaction region. The conical shape is challenging for NEG coating, because the coating parameters must be adapted to have a sufficiently uniform thickness of the coating. An insufficient thickness would result in a reduced capacity of the NEG film after several activation processes. A thickness too large might result in film peel-off, possibly during the activation cycles, because of the differential thermal expansion between film and substrate, to which adds up the stress inherent in a sputtered film that translates in a shear stress at the film-substrate interface. Both phenomena are proportional to the film thickness.

The coating of the experimental chambers will be performed in a coating system almost identical to those employed for the LSS vacuum chambers [3]. In this system the chamber to be coated sits in vertical position inside a segmented, 8-meter long solenoid, the sputtering cathode being coaxial to the chamber. In this cylindrical magnetron configuration the coating thickness, for fixed sputtering plasma parameters, is inversely proportional to the local radius of the chamber to be coated, and of course proportional to the coating duration. In order to solve the problem of the coating thickness variation in conical chambers, it is possible make the coating in several steps of different duration over the length of the chamber, by turning on or off the different sections of the solenoid. Of course in some simpler cases it is also possible to search for a compromise coating duration resulting in an acceptable variation of thickness, of the order of three between the minimum and the maximum for example.

Another challenge presented by a few of the experimental chambers are some very steep conical sections, where a factor three or more diameter transition occurs over a length of a few hundreds of mm. In order to acceptably coat these cones, which moreover are usually at the end of very long chambers, some tests are ongoing to exploit the reduction of magnetic field occurring at the extremity of a solenoid that could partly compensate for the reduction of diameter, which would otherwise result in an excessive thickness.

The manipulation of the experimental vacuum chambers raises also uncommon challenges. Most are extremely fragile, because the wall thickness is reduced to the minimum necessary for stability. Moreover the chambers surrounding the interaction regions are made of beryllium, which raises safety concerns. Special tooling is being designed in collaboration with AT/VAC, in order to ease the manipulation for coating preparation, and which should be also reusable for final installation in the LHC pits. The delivery to the coating laboratory of the first ATLAS (central Be chamber), CMS (conical chamber) and ALICE (conical chamber with steep transition) chambers is expected for the Summer 2004.

4 REDUCTION OF THE LOCAL BEAM IMPEDANCE BY CONDUCTIVE COATINGS

The transverse and longitudinal beam impedances in a particle accelerator are related to the surface impedance of the components facing the beam, which in turn is proportional to the electrical resistivity of the material. In several locations of the LHC machine are present components surrounding the beam that are poor electrical conductors or even are non metallic, raising deep concerns for the local beam impedance. Among these components we select the graphite jaws of the collimators and the BN blocks of the TDI injector collimators to illustrate the typical problems that may arise.

The 62 LHC collimators [4] will be made of graphite or carbon-fibre reinforced graphite blocks, which can be precisely adjusted to intercept the beam halo down to a width of $\pm 6\sigma$ (± 1.2 mm). This very small aperture results in a very strong effect of the collimator material on the local impedance, since graphite-based materials have electrical resistivity roughly three orders of magnitude higher than copper. To overcome this problem, a thin metallic layer can be deposited on the graphite surface. Since the surface is exposed to intense particle bombardment, the material choice and its thickness are the result of a compromise between impedance and heat generation by particle bombardment, which should not lead to melting or evaporation. The final choice is a layer of copper 5 μm thick. In order to deposit copper on graphite blocks of the size required for the collimators, a newly refurbished large-size magnetron sputtering plant will be used (Fig. 4). To enhance the adhesion of the copper layer to the graphite, a titanium underlayer of a few tens of nm is deposited first, followed by the copper coating. Tests have shown that the adhesion is in fact limited by the graphite cohesion, which can also be improved at the surface by CO_2 snow blasting. First prototypes will be coated during the summer 2004, while the full series production will likely take place in 2005.

A similar problem is presented by the TID injection collimators. In this case the coating of choice is titanium for its adhesion properties on hexagonal-BN, since the low frequency impedance requirements are satisfied by the outer encasing of the TID, while the high frequency ones are less stringent compared to collimators due to the larger aperture and the shorter overall length of the devices. In this case the series production of more than one 100 blocks will start in fall 2004, and is foreseen to run for about four months.

5 CONCLUSIONS AND PERSPECTIVES

A brief overview of some of the coating projects that the TS/MME/SC section is carrying out shows that the thin film vacuum deposition technology plays an essential role in the manufacturing process of several special LHC components. It is worth underlying that most of these projects are the natural outcome of intense R&D carried out in the previous years, and built over the experience accumulated in several former projects. Applications for future accelerators such as CLIC are already on the horizon, and developments for those projects may start as soon as the burden of the LHC production is relaxed.

6 ACKNOWLEDGEMENTS

The challenges faced by the Thin Film coating laboratory could not be solved without the invaluable technical assistance of Holger Neupert and Wil Vollenberg.

7 REFERENCES

[1] C. Benvenuti, Part. Accel. 40 (1992) 43

[2] A. Rossi, N. Hilleret, LHC Project Note 674

[3] P. Costa Pinto, Proceedings of this Workshop

[4] R. Assmann, LHC Design Report, Chapter 18

FIGURES

Figures 1a and 1b: First prototype LHC cavity made at CERN and final assembly of a cryomodule containing four superconducting cavities equipped with main RF power couplers

Figure 2: Ceramic windows of LHC main RF coupler after final coating

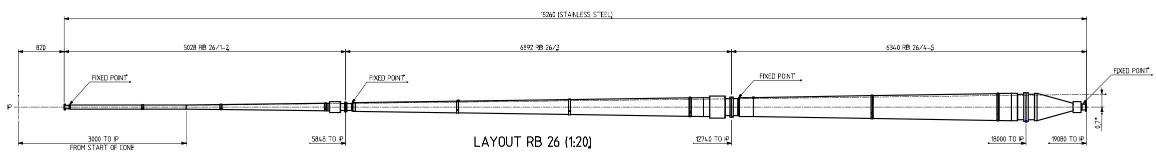

Figure 3: Overall layout of the ALICE experimental vacuum chamber

Figures 4a and 4b: New sputter system for the coating of the graphite jaws of the LHC collimators, and view of the sputter source and of the plasma during coating of a mock-up piece