

# MECHANICAL DESIGN OF THE INTENSITY MEASUREMENT DEVICES FOR THE LHC

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## Abstract

The intensity measurement for the LHC ring is provided by eight current transformers ( $2 \times \text{DCCT}$ ,  $2 \times \text{FBCT}$  per beam). The measurement resolution of  $1 \mu\text{A}_{\text{rms}}$  at 1s average for the DCCTs and  $\pm 10^9 \text{p}$  in 25ns for the FBCTs is required. Such constraints call for low noise electronics and a compact magnetically shielded mechanical design. Correct integration of these devices into the vacuum system also requires the vacuum chambers equipped with the non-evaporable getter (NEG) film. The NEG is activated by heating the vacuum chamber to  $200^\circ\text{C}$  and more. Such temperatures affect the structure of the magnetic materials, which form the base part of the intensity measurement devices, and degrade their performance. A cooling circuit is needed. Due to the mechanical constraints, the cooling circuit, as well as heating element must form an integral part of the design. The aim of this paper is to present the solutions to these problems and discuss the mechanical construction of the DCCTs and FBCTs currently being installed in the LHC.

## INSTALLATION OVERVIEW

The intensity measurement for the LHC ring is provided by eight current transformers. There are two DC current transformers (DCCT) and two fast current transformers (FBCT) installed on each vacuum chamber of the circulating beam. In addition, two supplementary FBCTs are installed on each beam dump transfer line. While the FBCTs for the dump and circulating beam are the same, the installation of the dump transformers differs from the installation of the ring transformers. The difference is given by the lack of the NEG coating and water cooling circuitry for the dump transformers.

The transformers for the ring measurements are installed in the LHC IP4, at the right side, approximately 160 metres away from the central point. The installation (fig. 2) consists of a 12 metres long girder which is used in common by the DCCTs and FBCTs. The monitors are fixed on the support in four sections. Adjacent sections are connected via a standard 80/84mm vacuum chamber. Each section is composed of two monitors of the same type and their vacuum chambers, installed symmetrically around the fixed point flange. The fixed point flange assures longitudinal fixation of the two vacuum chambers. In order to suppress mechanical forces acting on the ceramics and originating from baking and alignment, bellows are installed at both extremities of each section. Reduction of the impedance mismatch is

achieved by RF fingers installed at the interior of each bellows.

Such setup of the monitors has several advantages. Having common design of the support, fixed flanges and the vacuum chambers reduces design complexity and cost. The proximity of the DCCTs and FBCTs gives us the possibility of cross-calibrating the two equipments. It also allows the arbitration of the intensity values sent to the machine protection system. By connecting each monitor from the section into a different VME crate one can improve the availability of the measurement while keeping the cost reduced.

## THE VACUUM CHAMBER

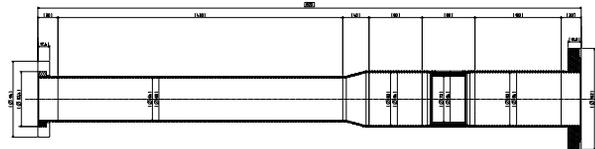


Figure 1: Common vacuum chamber for the DCCTs and FBCTs. Long parts are made of OFS copper, brazed parts are made of OFE copper electron welded to the OFS parts. There are 4 brazing parts: two at the extremities of the ceramics and one per each flange.

Due to the presence of the NEG coating and need for its activation, both measuring systems must be equipped by cooling circuitry protecting the transformer cores against excessive temperatures during bake-out. This, together with the requirements for the compact size lead to the design of the vacuum chamber having a partially reduced diameter, as seen on the figure 1. The reduction from standard diameter of 80/84mm to 64/68mm introduces a minimal risk with respect to the increase of the radiation and permits us to install a heatsink and heating element over the reduced diameter, still keeping the internal diameter of the toroidal transformer minimal with respect to the standard vacuum chamber diameter. The conical section between the standard and reduced diameter eliminates sudden longitudinal impedance changes. The slope of the section is  $11^\circ$ . Such a vacuum chamber configuration is satisfactory for the DCCTs which can operate with the ceramics outside of the measurement device. However, the FBCTs need to be installed over the ceramics gap during the measurement in order to assure the shortest possible RF path for the wall image current. This requires that the FBCTs are installed over the cooling tank during bake-out, and moved to the measurement position once baking is finished. Due to this

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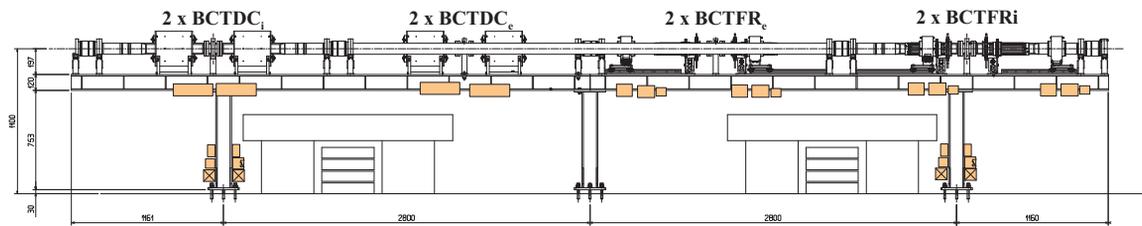


Figure 2: Installation of the intensity measurement devices in the LHC ring. There are four sections of the transformers, each section contains two transformers connected by fixed flange.

fact any mechanical obstacles, preventing the FBCTs from moving must be avoided.

The vacuum chamber is made of OFS copper. This eliminates the need for diffusion of supplementary copper layer at the interior of standard INOX vacuum chamber. The connection of the ceramics to the INOX vacuum chamber was replaced by brazing of the vacuum chamber directly to the ceramics by using OFE copper collars. The ceramics (WESGO Ceramics, type AL300) is metallised by  $25\mu\text{m}$  MoMn at the brazing places. The diffusion of the resistive layer ( $\text{TiO}_2$ ) on the interior of the ceramics was necessary in order to avoid the deposit of the charges, and to dump resonances caused by the volume of the FBCT outer shell. For the DCCTs the nominal resistance of  $10\text{k}\Omega$  was chosen. The resistance of  $25\Omega$  for the FBCTs was found to be optimal with respect to ringing of the FBCT output signal. Results of the measurements are depicted at figure 3.

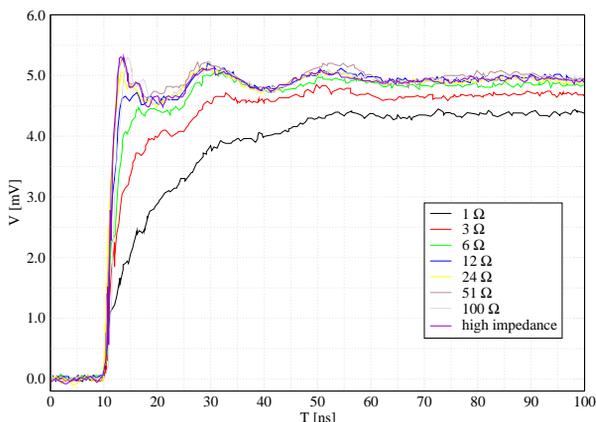


Figure 3: Time-domain measurement of the FBCT output signal for different resistive load on ceramic gap.

### DC CURRENT TRANSFORMERS

The principal layout of the DCCT is shown at figure 4. The device is permanently installed over the cooling tank (pos. 1). Physically the cooling tank is built of two copper half-cylinders to which the cooling pipe is brazed. These cylinders form 2 separate water circuits per DCCT. The internal section of the cooling pipe is  $4\text{mm}^2$ , which permits water flow of more than  $2\text{l/min}$ . By experiments it

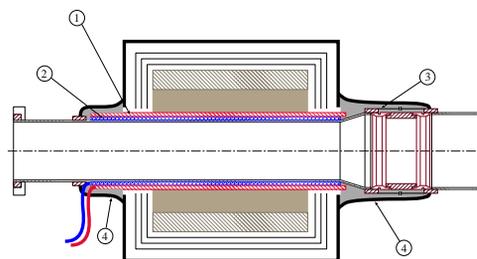


Figure 4: The sketch of the DCCT transformer.

was found that the flow of  $1\text{l/min}$  is satisfactory to keep the temperature in the inner parts of the DCCT shell well below  $40^\circ\text{C}$  when using  $200^\circ\text{C}$  baking temperature. The baking layer and corresponding isolation is permanently fixed on the vacuum chamber (pos. 2) as well. In order to ensure correct conditions during the bakeout temperature and water-flow detectors are installed and connected to the interlock of the heating system.

The internal diameter of the DCCT is  $114\text{mm}$ . It permits to keep the mechanical parts of the DCCT isolated from the vacuum chamber and cooling elements, and also allows to dismantle the vacuum chamber and DCCT separately. This is assured by usage of demountable flanges at reduced diameter side of the vacuum chamber. The transformer cores are custom built, by using Nanophy magnetic material from Mecagis-Imphy, installed into provided fiber glass supporting rings.

The magnetic protection of the transformer cores is formed by three Mu-metal layers. In order to increase the magnetic permeability of the material after machining the layers were temperature treated [1]. This is needed due to the loss of permeability during machining disrupting the alignment of the material's grain. The Mu-metal was annealed at  $1080^\circ\text{C}$  during 1 hour under vacuum and let to be naturally cooled down. The physical protection of the DCCTs is realized by a thick Armco layer serving as external housing. It serves also to prevent the Mu-metal shielding against the saturation in case of high magnetic field perturbation. The Armco material was temperature treated at  $980^\circ\text{C}$  during 1 hour in vacuum. Temperature controlled cool-down of  $100^\circ\text{C}$  per hour was necessary. Sand blasting and cadmium coating followed the thermal treatment in order to protect the Armco housing against rust. A cadmium

layer thickness of  $20\mu\text{m}$  was chosen.

The RF component of the wall image current passes through the DCCT via a series of capacitors placed around the ceramic gap (position 3 at figure 4). The LF component passes via the Armco shielding connected to the vacuum pipe by copper braids (4). The modulation frequency of 200Hz was chosen in order to ensure the compatibility with previous installation. The value of the by-pass capacitor can be up to  $1\mu\text{F}$ .

### FAST CURRENT TRANSFORMERS

The demand of placement of the FBCTs over the cooling tank during baking results in complex mechanical design shown at figure 5. The monitor itself (pos. 1) is fixed by rolling wheels to the HEPCO rail (2). The connection assures smooth and easy realignment of the transformer when moving from one position to the other one. It is also used to fine adjust the vertical alignment of the device with respect to the beam. During the bakeout the transformer is placed

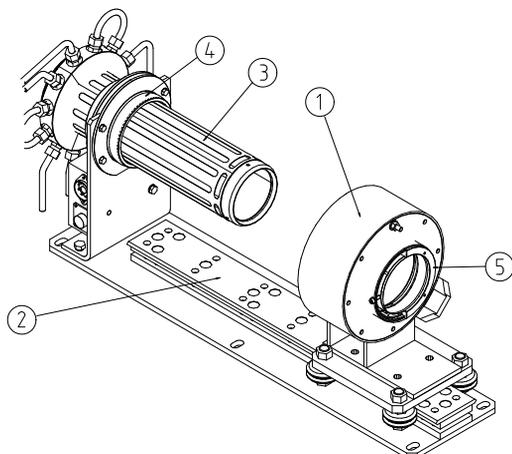


Figure 5: Mechanical design of the FBCTs used for the measurement in the LHC rings.

over the cooling tank (3) and pushed to the switch contact (4) realized by the flange made of fiber glass equipped with RF contacts. The RF contacts are connected to the bakeout interlock system and do not permit baking when the transformer is not correctly placed on the cooling tank. The cooler is composed of three independent parts, allowing water flow of more than  $4\text{l}/\text{min}$  per part. It is connected via water flow meters into the LHC general water distribution system.

During the measurement the transformer is fixed by four half-collars (5) to the vacuum chamber. In addition to the mechanical fixation they serve also as the RF signal path between the vacuum chamber and external shielding of the transformer. To assure good electrical contact the collars are made of copper covered by a  $10\mu\text{m}$  thick silver layer. The collars are mounted between the vacuum chamber and the transformer shell by using RF contacts. At the place of

the connection the vacuum chamber is treated with silver painting. As in the case of DCCTs, the outer shell of the FBCTs is made of Armco, however instead of cadmium treatment the shell was galvanically silvered. The thickness of the silver layer is  $10\mu\text{m}$ .

The monitor itself is composed of two independent transformer cores covering different frequency ranges. The sketch of arrangement is shown on the figure 6. The high-frequency core (1) is 1:40 turns low-droop Bergoz transformer, covering the frequency range from 400Hz to  $\approx 1\text{GHz}$ . The low-frequency core (2) is made from Vitroperm 500F and equipped with 120 turns. Its low-frequency cut-off of 22Hz provides us with additional information which will be used in the recovery of the DC component of the measured beam signal. Mechanical fixation of the two cores is provided by a 5mm thick fiber glass layer (3) on which the calibration turn circuit (4) is fixed. The calibration circuit is realized by a set of resistances and microstripes distributing the calibration current equally into 8 parallel calibration turns, appearing at the input as a  $50\Omega$  single calibration turn. To ensure good impedance characteristics the calibration circuit is made of 0.3mm thick RF material Neltec NY9220.

The electronic part of FBCTs is inserted into the Mu-metal shell (5) protecting the transformers against external low-frequency magnetic fields. The annealing process was applied as in the case of DCCTs. The entire construction is placed into the Armco housing and centered by system of a 3mm thick printed circuit boards (6). The centering boards are copper plated at both sides and electrically connected to the Armco housing. Position (7) in the figure 6 shows the placement of the RF half-collars already mentioned.

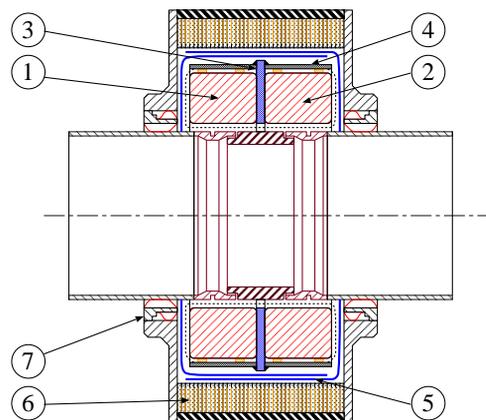


Figure 6: The sketch of the FBCT monitor for the LHC

### REFERENCES

[1] P. Odier, "Proposal for three Beam Current Transformers for CNAO", AB-Note-2004-067, CERN, Switzerland, September 2004.