INDUSTRIAL PRODUCTION OF THE EIGHT NORMAL-CONDUCTING 200 MHZ ACN CAVITIES FOR THE LHC

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Abstract

The LHC-ACN RF system consists of 8 normal-conducting cavities and is designed to reduce beam losses in the LHC when injecting beams with longitudinal emittance > 0.7 eVs from the CERN SPS. The cavity design took into account the possibility of recuperating all the "ancillary" equipment (tuners, fundamental mode damper, High Order Mode (HOM) couplers) from the old CERN SPS 200MHz system. The cavities are made from OFE copper. The original ingots, procured in Austria, have been forged and pre-formed by pressing them with a 20 tons press, following a procedure defined and adapted for the unusual dimensions of these pieces. The raw components thus obtained were machined and then welded together with an electron beam. In order to get a good repeatability of the fundamental mode frequency across the eight cavities, a procedure has been established with the contractor for the final machining and welding leading to a spread in frequencies below ±20 kHz (< 0.01%). The cavities will be installed in the LHC when losses at high intensities become significant. In the meantime they are undergoing a surface treatment to clean the RF surface and will be stored.

INTRODUCTION

The LHC main RF system is made of eight 400.8 MHz superconducting cavities per beam, identified as the ACS system. These cavities will provide up to 16 MV of acceleration per beam. The ACN system is made of four normal conducting 200.4 MHz cavities per beam [1] and has been foreseen to capture the long bunches coming from the CERN SPS at 450 GeV and transfer them into the smaller 400.8 MHz bucket minimizing beam losses. The decision to build the ACN cavities was taken in 1999. The RF and mechanical design were carried out in parallel by doing coupled simulation in ANSYS® [2]. The advantage of doing that is the possibility to take into account with a high level of precision (better than 1% error) all the effects of mechanical deformations on the frequency of the cavity [3] (in particular vacuum and heating), and to prevent them by identifying the most critical parts and modulating the thickness of the cavity walls accordingly. The water cooling channels have also been designed and checked through simulations. The contracts for the supply of the raw material, forging and manufacturing were signed in 2001, and the eight cavities are now at CERN and have been tested for frequency and vacuum tightness.

In the meantime intensive studies to lower the impedance of the CERN SPS have led to a significant reduction of the bunch length at nominal intensity [4]. The urgency for the installation of this capture system is therefore reduced, and the project management has taken the decision to install the ACN system at a later date when the intensity will approach the ultimate. A complete power system will be anyway installed in a test stand outside the tunnel to power test the cavities and develop the low level controls, but the eight RF chains for the tunnel will only be purchased at a later stage.

This paper describes the manufacturing process for the cavities, starting from the supply of the raw copper, forging of the ingots and final machining and welding.

RAW COPPER AND FORGING

The contracts for the supply of raw material and forging were based on the CERN specification for oxygen free copper (OFE) and a need to have a small grain size to avoid vacuum leaks in the interstitials among the grains at Ultra High Vacuum level (in the LHC the maximum pressure allowed is 10^{-9} mbar), and good mechanical and thermal properties. The raw material was supplied by Montanwerke Brixlegg AG (Austria) and forged by Carlier SA and Fortech/H.T.M. (France).

Fig. 1: The raw material before forging.

Forging was a critical step in the project. The process was carried out in two steps. The first is done by heating the material to reduce the grain size and increase the compactness of copper. The second is done by keeping the material cold, to keep the grain size small, and by pressing the material with a 20000 Tons press to reach the mechanical characteristics required by our application. The unconventional dimension of the ingots (ϕ 410 mm *

Fig. 2: a) The end-cap with the nose cone; b) the central part on the nose cone, c)the three pieces assembled vertically before machining and welding in order to perform the measurements.

1470 mm) required a special set-up to avoid buckling. At the end of the contract, of a total of sixty pieces, only three had to be rejected.

MANUFACTURING AND WELDING

The shape of the cavity has been designed taking into account several needs: first of all the external radius of the cavity has to be less than the separation between the two beams in the RF straight section at point 4 of the LHC (420 mm) where the cavities will be installed. From the RF point of view the small diameter of the cavity leads to an important dissipation of the electromagnetic energy stored in the cavity to sustain the accelerating gradient of 750 kV CW. Therefore the cooling channels have to be efficient and quite densely distributed to maintain the temperature of the cavity at an acceptable level. The specification for the cooling circuit is $\Delta T<20^\circ C$ for an accelerating voltage of 1 MV. At this level 87 kW CW have to be evacuated via the cooling water. As mentioned above, the design has been carried out with ANSYS® using coupled mode analysis, which allows transferring immediately the effect of the RF power dissipation into the mechanical structure.

A further requirement concerned the frequency of the Higher Order Modes (HOM) of the cavities, which have all to be far enough from the beam lines to minimize the power transferred through the HOM couplers by the beam. The most prominent monopole and dipole HOMs have been evaluated through simulations and measured on a bare cavity and should be sufficiently far away from the beam lines in the final design. However, in the future High Power test, we will check again the frequencies that might be changed by the introduction of the various ancillary equipment.

The cavity itself is made of three parts, the two endcaps and a central cylinder (fig. 1), that had to be welded together by Electron Beam Welding (EBW). Each of these parts was itself made of several pieces, a basic structure with the RF surface on one side and the grooves for the cooling channel on the other side, with several parts welded onto it using EBW to close the cooling channels and have a leak tight water circuit. All the water channels have been leak tested up to 6 bars. After the welding of the cooling channel covers, the parts were machined to reach the nominal dimensions and finally the three main components were welded together by EBW. Due to the absence of a wide-range tuner to compensate the mechanical tolerances, we had to carefully control the final welding procedure by machining away a sufficient amount of the extra longitudinal length (+4mm) added on each side of the central cylinder for this purpose. The correct additional length was decided for each cavity first by measuring the frequency of the cavity before any weld, then by estimating the welding shrinkage from measurements on welding tests, and finally by measuring exactly the sensitivity of the cavity to length variations. For this last parameter (125 kHz/mm) we had a very good agreement between measurements and simulations. A first session of measurements took place at CERN in July 2002 to determine the detuning introduced by the tuners, HOM Couplers, Power Coupler and vacuum. By knowing these parameters, we used the following procedure to evaluate the length to be machined away to reach the goal frequency of 200.213 MHz for the bare cavity at Normal Temperature and Pressure (NTP) (the frequency during operation will be 200.394 MHz):

1. Assume that

   $$\frac{\Delta f}{\Delta \ell} = -125 \frac{kHz}{mm_{(cutaway)}}; \quad \Delta f_{Weld} = -200\ kHz$$

   these values were confirmed by measurements;
2. Measure the frequency f_{meas} of the bare cavity assembling the three components vertically. The RF contact is ensured by the quality of the surface, the weight of the components themselves and by an RF seal.
3. Compute the length to be removed on the first side with the formula:

   $$L = \frac{1}{2}\frac{\left[200.213MHz - f_{meas} - (2 \cdot \Delta f_{Weld})\right]}{\Delta f / \Delta \ell};$$

4. Measure the frequency after machining (for all the cavities the length removed was within tolerances: ±0.3 mm);
5. Weld the first side;
6. Measure the frequency $f_{1stweld}$ of the cavity to check the shrinkage and decide the length to machine away with the following formula:

   $$L = \frac{\left[200.213MHz - f_{1stweld} - \Delta f_{Weld}\right]}{\Delta f / \Delta \ell}$$

7. Check the frequency after machining (results as for point 4);
8. Do the final welding;
9. Measure the final frequency.

Tab. 1: Final Frequency of the bare cavities at NTP.

Cavity	Frequency [MHz] at NTP
1	200.210
2	200.218
3	200.206
4	200.211
5	200.198
6	200.214
7	200.212
8	200.213

The procedure was applied directly at the contractor's premises (Ettore Zanon, Italy), after a preliminary measurement phase of the first cavity at CERN [5]. After the first cavity, the others were produced in batches of two and the whole procedure could be applied to both cavities in a week. The final results are impressive for the repeatability of the fundamental frequency (see tab. 1):

With respect to the goal frequency the maximum error is therefore -15 kHz (<-0.01%). No remarkable non-conformities were observed during the final production. Due to the large dimensions, the contractor was not asked to carry out a final polishing of the internal surface. Only a manual cleaning of the welding projections using Scotch-Brite^{TM} and a soft degreasing were applied. At CERN we made a more aggressive degreasing using ultrasound in a slightly acid bath. After that the cavities were stored under Nitrogen waiting for the future power test.

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