The Winding Line for the CMS Reinforced Conductor

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***Abstract*--The Compact Muon Solenoid (CMS) is one of the general-purpose detectors to be provided for the LHC project at CERN. The design field of the CMS superconducting magnet is 4 T, the length is 12.5 m and the free bore is 6 m. The use of a reinforced conductor for the CMS coil required a sustained activity of development at industrial level, to understand how to handle, to pre-bend and to wind the conductor with an inner winding technique. The winding line was designed and constructed according to this experience. The working principles of the line are under test through the winding of a prototype of a CMS coil module. The prototype has the same radius of a CMS module (6900 mm outer diameter), but a shorter axial length (670 mm against 2500 for the module). The critical operations are related to the accurate pre-bending of the conductor, the positioning of the turns into the winding, the axial compaction, and the correct handling of 50-ton windings.**

***Index Terms*--Al stabilized conductors, Detector Magnets, LHC project, Winding.**

I. Introduction

THE Compact Muon Solenoid (CMS) is one of the experiments under construction in the framework of the Large Hadron Collider (LHC) project at CERN. The design field of the CMS magnet is 4 T, the magnetic length is 12.5 m and the free bore is 6 m [1], [2]. As reported in previous papers [3], [4], [5], the main peculiarity of the CMS solenoid, among existing thin solenoids for detectors, is its conductor: a ‘standard’ conductor, made from a Rutherford cable co-extruded with pure aluminum, is mechanically reinforced with aluminum alloy. The coil was designed according to the idea to have a mechanical self-supporting winding. The complete coil is made of five modules, mechanically coupled and electrically connected in series. The construction of the main components of the superconducting coil is progressing under the control of the CMS Coil Collaboration. In particular the winding of the 5 modules is started at Ansaldo Energia under contract of INFN-Genova. The CMS reinforced conductor required a development at an industrial level of the methods and the tooling for the winding [6].

The pre-industrialization led to the design and the construction of a complex winding line, finalized to bend and wind the stiff CMS reinforced conductor. The line has been successfully tested using a dummy EB-welded reinforced conductor [7].

Activities are now in progress to wind the prototype module (same diameter but shorter axial length).

The paper discusses the main topics related to the winding line, especially the pre-bending operations, the new method for positioning the turns inside the winding, the axial compactation systems and all other devices involved in the winding line.

II. Winding Line Lay-out

The winding line was designed according to the basic principles of inner winding method. A thin (50 mm thick) Al-alloy mandrel is put in rotation, while the conductor is pre-bent and positioned inside the mandrel or an existing layer. The basic idea in designing the line, according to pre-industrialization experience, was to form one turn in air and then transfer it inside the winding through a continuous process. The line can be divided in two main parts: The conductor preparation line (aimed to form one turn) and the transferring system, positioning the formed turn inside the winding.

The preparation line is composed by the following devices: a) De-spooling unit, able to support the 10 ton spool containing the conductor length of 2.5 km; b) Straightening unit; c) Milling machine, to prepare conductor exits for electrical joints, d) Cleaning unit with solvent and ultrasonic waves; e) Bending unit, which will be shown in detail in later section; f) Sand-blasting unit g) Taping unit.

The transferring system includes: a) Fixed and rotating table, supporting and rotating the module during winding; b) Conductor driving unit, which carries the pre-bent turn from the top to its position in the winding; c) Conductor positioning system, which deposits the conductor inside the winding; d) Pressing system, for axial compactation of the winding.

The winding line also includes the support structure of the components and all ancillary plants.

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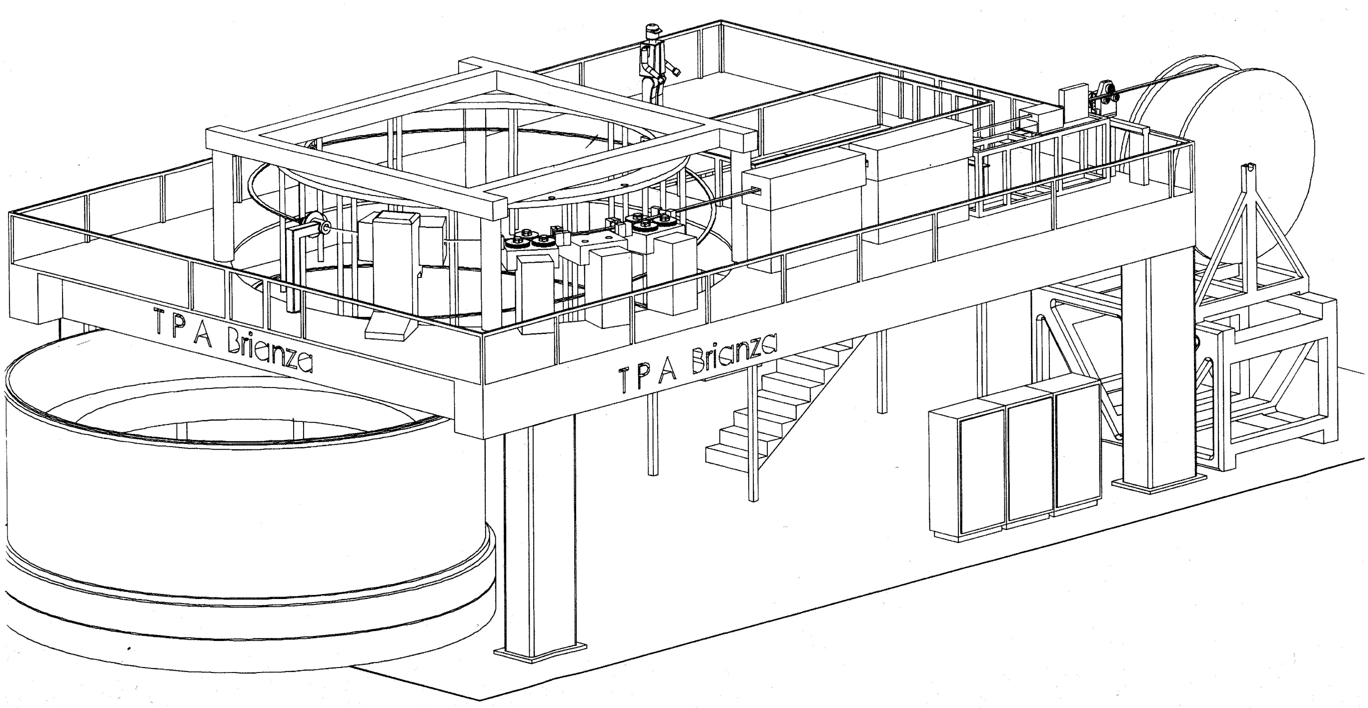

Fig. 1. Artistic view of the winding line, according to the first design.

An artistic view of the winding line and part of its components can be seen in Fig.1, according to the first design carried out at TPA Brianza (sub-supplier of Ansaldo).

III. Conductor Preparation Line

A. De-spooling and Straightening

The reinforced conductor, after EB-welding, is wound on a 10 ton spool on its lower inertia. The first action of the preparation line consists in de-spooling the conductor and making it as straight as possible. This latter operation is done using the unit shown in Fig. 2, involving many rollers in both vertical and horizontal direction. The unit is controlled by a processor driven by the conductor movements.

B. Milling machine

The 4 layers composing a module shall be connected electrically in series; the joints are placed outside the winding, mechanically attached to the mandrels. With this aim, the two extremities of each layer must be prepared for the electrical joint [8], removing the Al-alloy for some length. Though this operation is done at the beginning and at the end of a layer, it is anyway necessary to have on line a dedicated milling machine, shown in Fig. 3.

C. Cleaning unit

In order to have a conductor surface prepared for adhesion through epoxy resin [9], as first step any impurities shall be removed from it. This is done passing the conductor through a solvent bath coupled with ultrasonic device.

Fig. 2. Straightening unit.

Fig. 3. Milling machine, placed aside the cleaning unit.

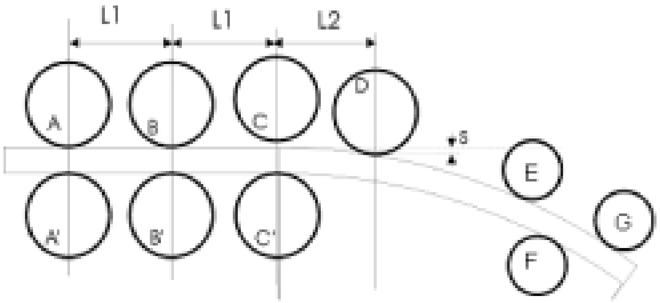

Fig. 4. Working principle of the two-step bending unit. Rollers A, A' drive the conductor. Rollers B, C' and D bend the conductor at a radius R_1 (Roller B' and C are not active). Rollers E, F and G bend the conductor at the final radius $R_2 < R_1$.

Fig. 5. The constructed two-step pre-bending unit under test.

D. Bending Unit

The pre-bending is a crucial operation for the winding of a stiff conductor. Any failure causing radius variation, short waves or twisting would result in winding imperfections (voids are created inside the winding). A progressive bending is done (two-steps bending) according to the principle shown in fig.4. The unit is shown in Fig. 5.

E. Sand-blasting and Taping

After bending the conductor surface is sandblasted to maximize the adhesion surface. Also this operation is done on line as the following insulation operation, done by wrapping two fiberglass tapes half-overlapped. The sandblasting and wrapping units are shown in Figs. 6 and 7.

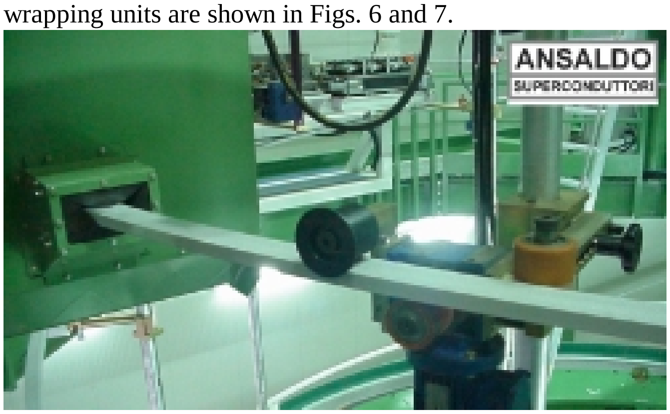

Fig. 6. Conductor coming out from sandblasting unit during operation.

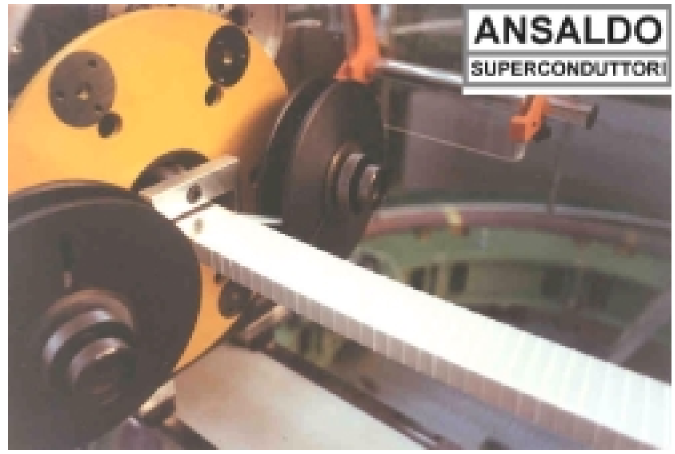

Fig. 7. Taping unit mounted in the winding line.

IV. Transferring System

A. Winding Table

This component, made of several parts, has the role to support and rotate the winding, to lift it. Fig. 8 shows the fixed table supporting the rotating table. Both tables can move in vertical position (through the large rods attached to the central structure), so to have the winding configuration not changing during the winding operations.

B. Conductor Driving Unit

This unit is a structure made of rods and motorized rollers, driving the insulated turn, from the top of the mandrel to the turn location inside the winding.

C. Conductor Positioning System

Once each turn is led to approach the winding (internally against the mandrel or existing layer), it is necessary to push it longitudinally and radially. This is done by a special unit, working as three hands, which clamp the conductor and push it. The system is always kept (by a hydraulic circuit) in operation, so to avoid releases of turns (Fig. 9).

Fig. 8. Winding table with fixed and rotating parts and lifting system.

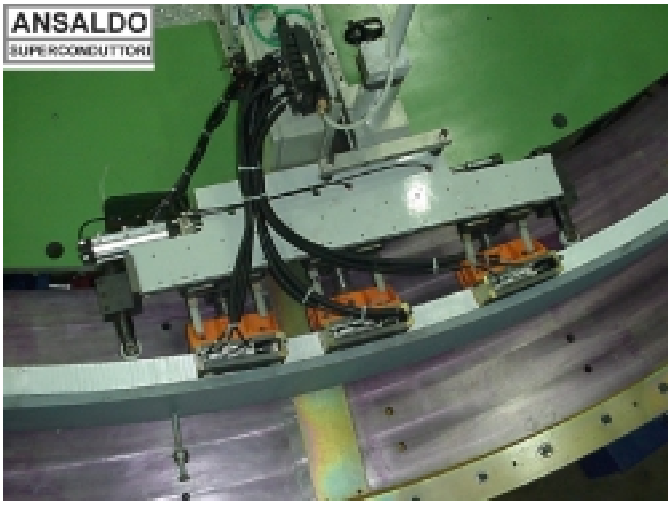

Fig.9. Conductor positioning device.

V. Tests

The complete winding line has been assembled inside a clean area and a series of test has been done to check the whole winding operation (Fig.10). Waiting for the completion of the prototype mandrel, a temporary steel mandrel has been used.

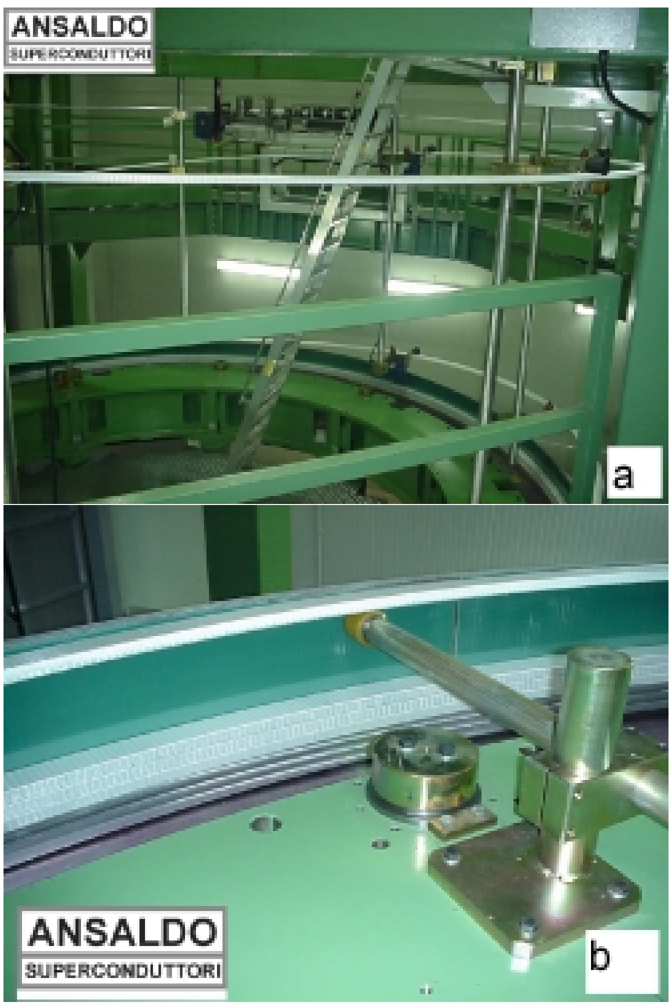

Fig.10. Dummy conductor after bending (a) and transferring (b).

Apart few modifications, the line is presently ready to start the winding of the module prototype, which has the same diameter of a real module, but reduced length (about ¼). The critical operations are the pre-bending and positioning of the turns inside the winding. In this frame the actual two-step bending device has demonstrated to work well. Small variations of conductor thickness (within 0.1 mm over 64 mm) or 10% variation in the mechanical properties of the Al-alloy reinforcement does not give rise to significant variation of the final radius. The three-hands system for positioning and pressing the conductor inside the winding seems work quite well. A longitudinal force of 2 kN is able to compact radially the turn under winding. This system also provides a continuous pressure of the turn under winding against the winding pack, for avoiding turn releases. Of course the construction of 4-layer prototype is aimed to confirm these results for long lengths of conductor.

VI. Conclusions

After two years of pre-industrialization activities and eighteen months from the start of the winding contract, the winding of CMS modules is on starting. The constructed winding line has demonstrated to be able to wind and pack the reinforced CMS conductor in correct way. The final proof is demanded to the winding of prototype involving 2.5 km conductor.

VII. References

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