SLHC-PP

DELIVERABLE REPORT

EU DELIVERABLE: 6.3.2

Document identifier:	**SLHC-PP-6.3.2-1093337-v1**
Contractual Date of Delivery to the EC	**End of Month 32 (Nov. 2010)**
Actual Date of Delivery to the EC	**30/03/2010**
Document date:	**30/03/2010**
Deliverable Title:	**Assembly of 2-m-long prototype quadrupole**
Work package:	**WP6: Development of Nb-Ti quadrupole magnet prototype**
Lead Beneficiary:	**CERN**
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Document status:	**Released**
Document link:	https://edms.cern.ch/document/1093337/1

History of Changes

Version	Date	Comment	Authors

The Preparatory Phase of the Large Hadron Collider upgrade (SLHC-PP) is a project co-funded by the European Commission in its 7th Framework Programme under the Grant Agreement n° 212114. SLHC-PP began in April 2008 and will run for 3 years.

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1. EXCUTIVE SUMMARY

This workpackage concerns the assembly of a 2-m-long model quadrupole magnet for the new inner triplet required for the LHC luminosity upgrade. The heat load from particle debris in the inner triplets calls for a new, more porous coil and ground plane insulation [1]; see also the report on Deliverable 6.2.1.

The collaring of the nearly 10-m-long quadrupole magnets cannot be done with the standard presses used for the long dipole magnets. The reason is that the four-fold symmetry of the quadrupoles has to be guaranteed in order to avoid non-allowed multipole field error in the aperture field. A novel self-locking collar pack design was therefore developed in 2009. These packs require a spring-loaded and collapsible assembly mandrel. This mandrel is also shown in the report on Deliverable 6.2.1.

The assembly of the magnet cannot be completed before all components are procured and all tooling is commissioned. While all magnet components for two magnet models have been procured from European industry, the tooling was only commissioned in late March 2011. The first set of production coils have been produced at CEA/Saclay, while trial coils have been manufactured at CERN. The next step is now to measure the elastic modulus with dedicated tooling (see also report on Deliverable 6.2.2) in order to validate the calculations of the final coil size. CERN and its partners are committed the finish the magnet assembly by autumn of 2011. The first magnet will mainly serve at the validation of the design concepts and will therefore be tested in a vertical cryostat. The second model aims at good field quality and will be tested in a horizontal cryostat, so that heat transfer and quench propagation measurements can be done in realistic conditions.

This report shows some of the procured components and presents the recently commissioned tooling. This is an investment not only for the production of MQXC magnets, but will also serve for future model work for superconducting quadrupole magnets.

2. PROCUREMENT OF COMPONENTS AND COIL MANUFACTURE

The MQXC magnet design takes full advantage of the features implemented in the CERN field computation program ROXIE [6]. In particular, the design and manufacture of the coil end-spacers follows the integrated approach with data transfer from ROXIE to CAD (CATIA) and the 5-axis CNC machining of the pieces. By means of trial coil windings both at CEA and CERN, the shape of these spacers was optimized. The production pieces (manufactured independently by two European suppliers) are shown in Fig. 1.

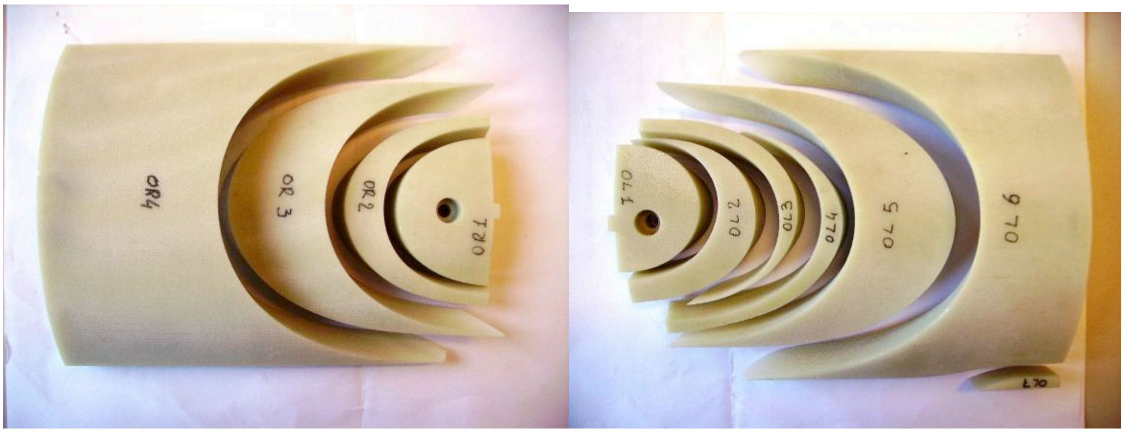

Figure 1: Production set of end-spacers for the outer layer coil of MQXC

After two iterations with trial coils, the optimum shape of the end spacers was established. It was found that the minimum bending radius on the cables broad face must be located at the nose of the end spacer. The coil ends of the first production coil are shown in Fig. 2. No gaps appear on the inner and outer diameter of the coil and thus potting of the coil ends can be avoided. This is important for the penetration of the helium and will thus improve the heat transfer across the laminated collars and yoke to the bayonet heat exchanger.

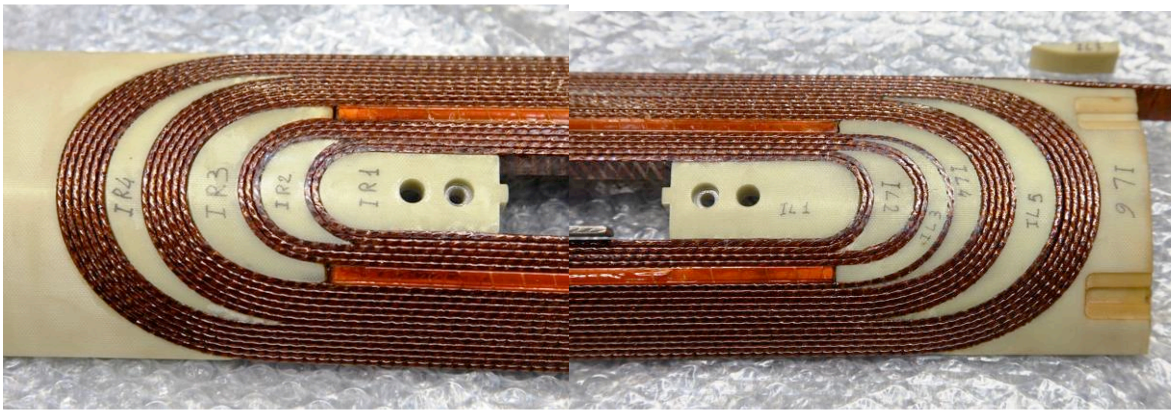

Figure 2: Extremities of the first (inner layer) production coil wound at CEA/Saclay. Left: Return end, Right: Lead end.

The coil winding is shown in Fig. 3. The coil is then subjected to a curing cycle described below. Fig. 4 shows the outer-layer coil after it is removed from the curing press.

Figure 3: Winding of the first production coil at CEA/Saclay.

Figure 4: Photograph of the first (inner layer) production coil for the MQXC quadrupole magnet produced at CEA/Saclay.

The collars were developed for the horizontal assembly technique. Under the press, all collars move in together so that they are self-locking and quarantee the 4-fold symmetry of the quadrupole coul. The collar shape was then modified to allow for passive magnetic shims to be inserted at a later stage between the collars and the yoke. These shims allow the compensation of non-allowed mutlipole field errors and are therefore known as “tuning shims”. Heat transfer was optimized by the stamping of dimples, in order to reduce the stacking factor to 94%.

The production of the collars was optimized to meet the required tolerances at minimum cost. In high tolerance edges (+- 0.02 mm) are electro eroded, while the “lower” tolerance edges (+- 0.07 mm) could be machined with the less expensive laser cutting. Each 2-m-long magnet will contain about 800 centre-section collars and inserts, as well as 430 end-section collars and inserts. The total production for the set of magnets will use comprise more than 4000 parts. The first production batches of these collars (centre and end-sections) are shown in Figs. 5 and 6.

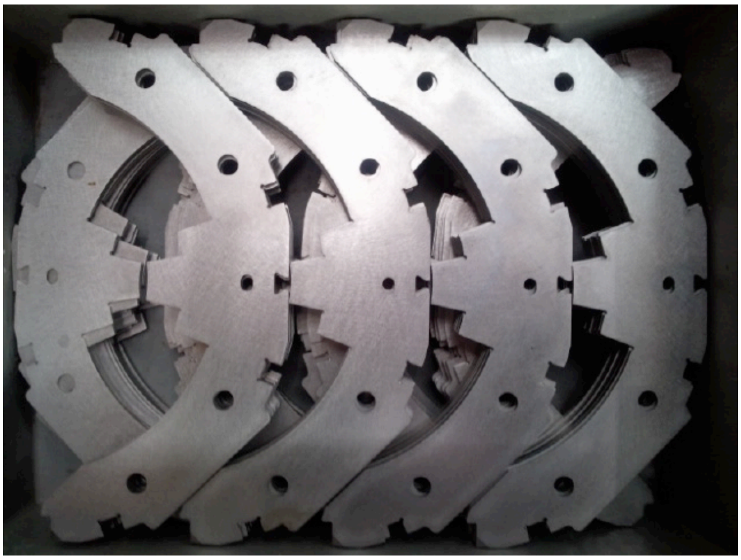

Figure 5: Production batch of collars for the central section of the magnet

The production method for the dimpled inserts was also optimized in order to avoid expensive fine-blanking tools. The dimples are first punched into the laminations with a dedicated press. The subsequent electro erosion of the edges neutralizes any possible deformation of the laminations due to the dimples, while they help to align stacks of laminations during electro erosion process.

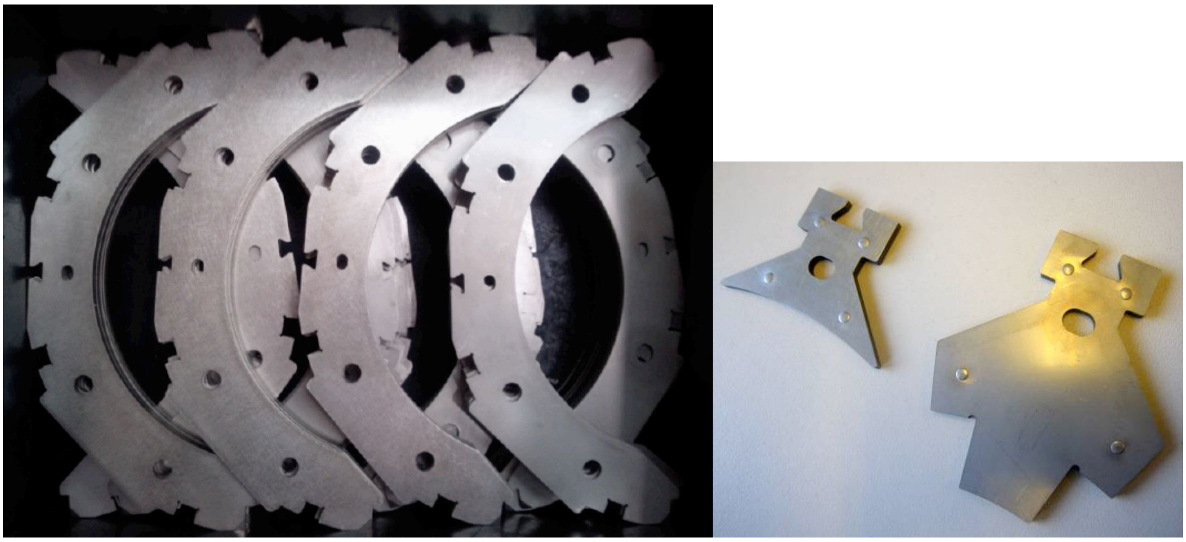

Figure 6: Left: Production batch of collar laminations for the end-section of the magnet (covering the coil ends with the G11 endpacers). Right: Insert collars with dimples.

The novel design for the quench heaters (a sandwich of two heaters for the inner and the outer layer coils) was already described in earlier report. The design guarantees faster heat up, and simultaneously, increased channels for the cooling medium. The in-house manufacturing includes chemical edging of stainless steel strip, pre-forming to the outer radius of the inner layer coil, water-jet cutting of holes in the Kapton strip, and electrical testing at 3 kV. The first production batch of 2-m-long heater strips is shown in Fig. 7.

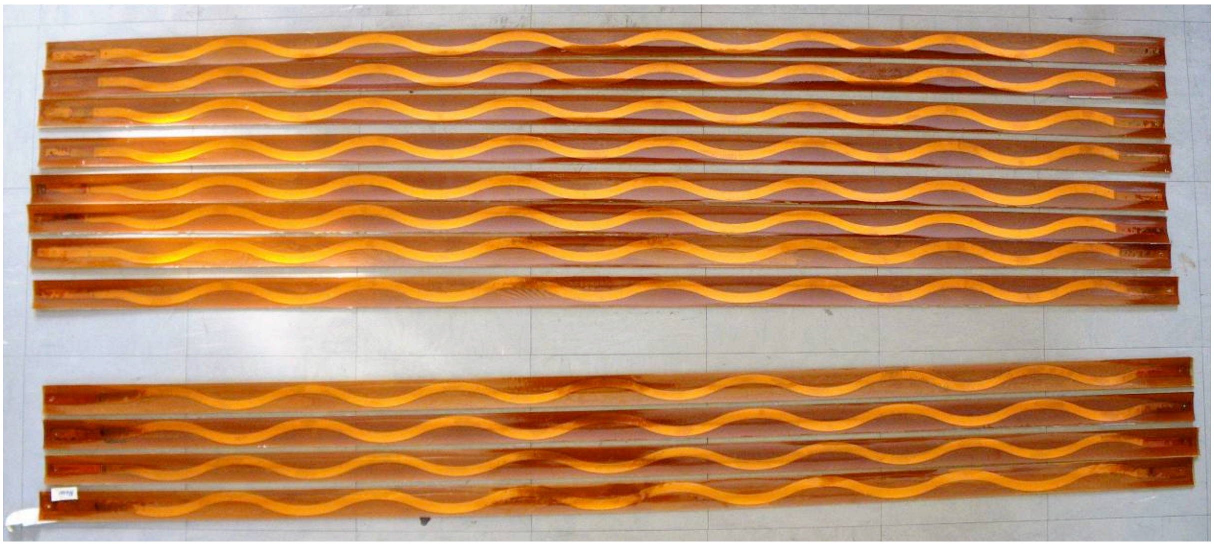

Figure 7: Production batch of quench heaters.

3. PROCUREMENT AND COMMISSIONING OF TOOLING

Fig. 8 shows the coil curing presses at CEA and CERN. New precision-machined inserts (the so-called moulds), which define the shape of the coil had to be procured. The heating system at CEA consists of electrical heating plates, while the CERN tooling uses a flow of heated oil. The insert used at CERN is shown in Fig. 9.

Figure 8: Left: Curing press for the 2-m-long superconducting coil at CEA/Saclay. Right: Curing press at CERN

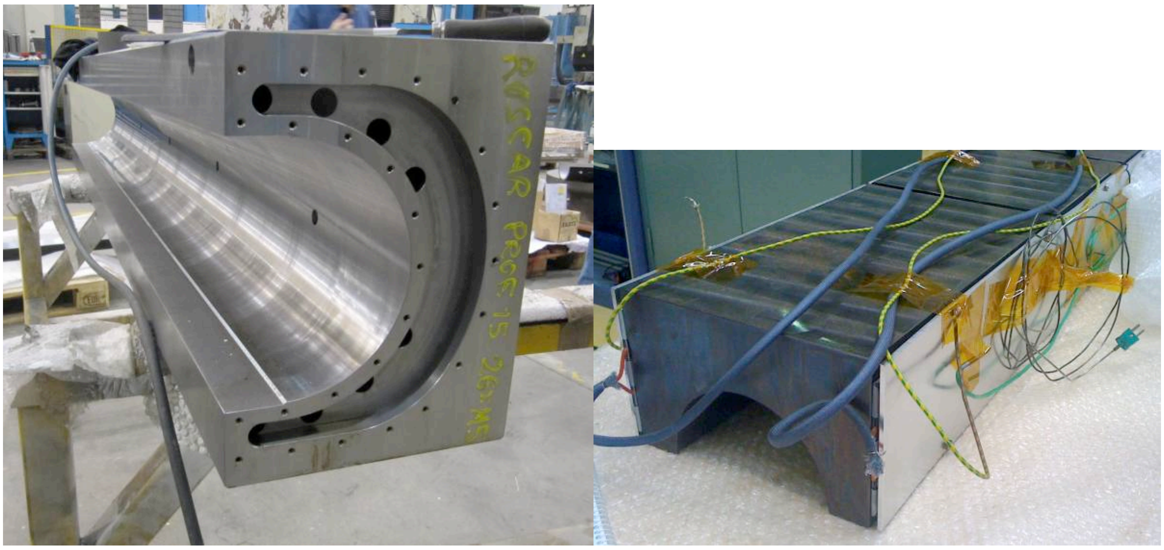

Figure 9: Left: Curing mould with channels for the oil heating. Right: Mould with heating plates

The heating system for the curing press at CEA provides a maximum power of 15 kW by means of 3 heating plates (with two fixed to the moulds and one fixed to the mandrel). For both the inner and outer layers of the 1.8-m-long MQXC coil, the same curing cycle (corresponding to the LHC dipole curing cycle) was used; see Table 1. The conductor stacks were azimuthally compacted to their nominal size determined by field quality optimizations. Fig. 10 shows the temperature evolution versus time at different parts of mould and the mandrel. The coil extremities are relaxed before the curing cycle and are tightened with screws M12 at 100 Nm, when the mould is closed at 135 °C.

Temperature T (°C)	**Hydraulic pressure (Bars)**	**Azimuthal stress s_q in cable (MPa)**	**Duration (Min)**	**Observations**
23	28	12	-	
60	45	20	-	
110	290 45	**s_q < 130** 20	10 -	Mould was closed at 290 bars after 10 min, return to 45 bars
135	290	**s_q < 130**	-	Mould was closed (up to 60°C) coil extremities were tightened
190 < T < 197	290	**s_q < 130**	30	Target temperature range
60	0	0	-	Mould opened and coil removed

Table 1: Curing cycle

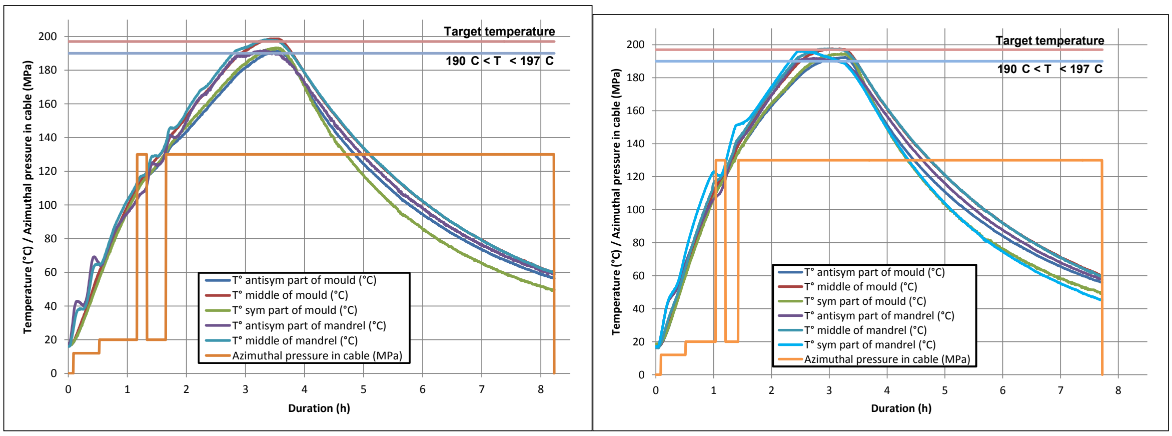

Fig. 10: Measurement of the coil temperature during the curing of inner layer coil (left) and outer layer coil (right)

The temperature regulation of the mould and mandrel are dissociated by means of 2 distinct PID temperature controllers. At any time, it is possible to impose the uniform temperature between internal and external radius of each coil layer.

The maximum target temperature in middle of the mould and mandrel must attain 197 °C in order to make sure to have the minimum target temperature of 190 °C at the extremities.

After curing, the measured length of both inner and outer layer is 1803 mm. Angular wedges were cut at nominal length before winding operation (1564 mm and 1446 mm for the inner and outer layer, respectively). This results in gaps of 1.0 mm for the inner layer and 1.9 mm for the outer layer between the wedges and the end pacers. This must be taken into account for realization of the production coil layers.

Once the coil size will be validated with the modulus test tools (see report on Deliverable 6.2.2), the coils can be mounted on the split assembly mandrel and then be clamped with the preassembled collars shown in Figs. 5 and 6. The assembly sequence of the magnet is shown in Fig. 11.

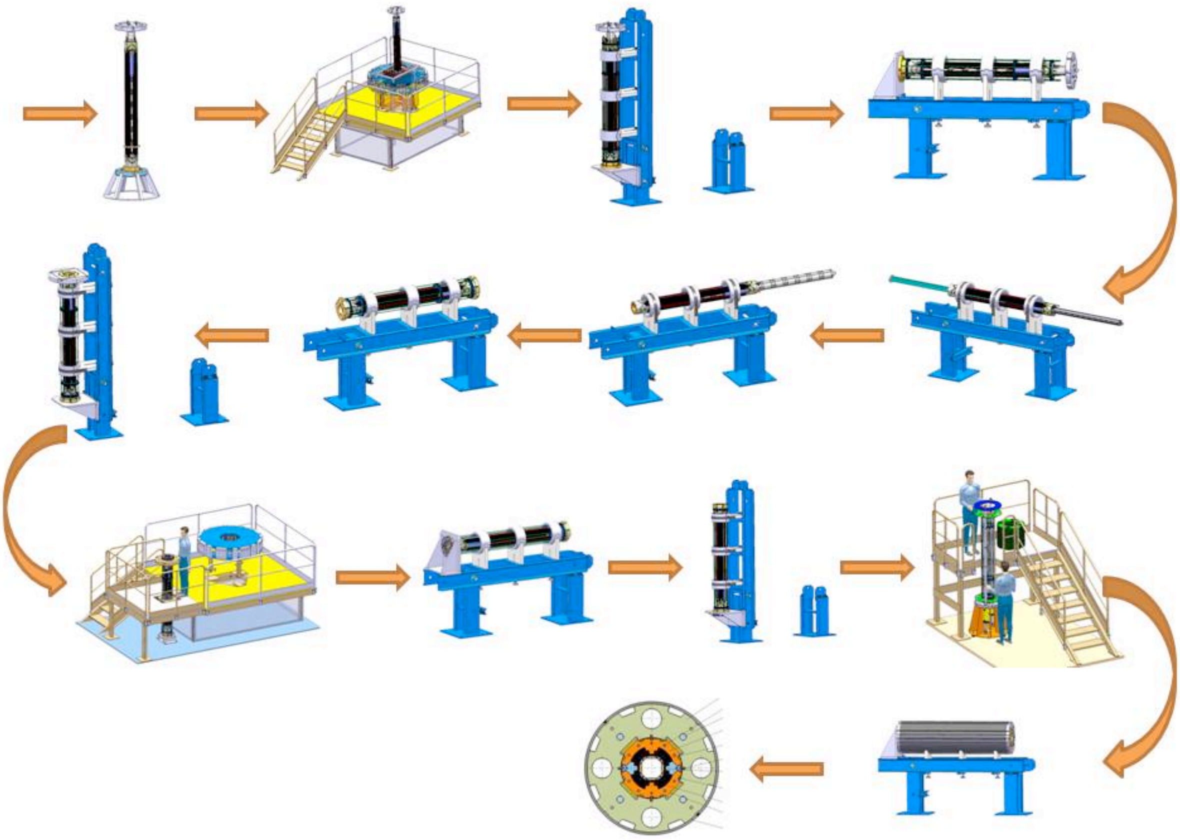

Figure 11: Assembly sequence of the MQXC quadrupole magnet

As has been said in the report of the second year, the assembly of the 10-m-long magnet cannot be done with the coil in vertical position. For this reason the collaring press was designed and manufactured such that it can be used also with the coil in the horizontal position. For this purpose the coil would need to be supported by an assembly table that was estimated to about 200 thousand Euros. This investment is not justified in view of the re-scoping of the SLHC-PP workpackage 6. The collaring press mounted on a platform and connected to the hydraulic system is shown in Fig. 12. Fig 13 shows the press anvils when the top support plate of the press is removed. The four-fold symmetry of the coil/collar pack is assured by the three sets of anvils for applying the pressure on the collar, for inserting the locking keys and for opening of the collar packs if this becomes necessary during the operation.

Figure 12: Collaring press with hydraulic elements

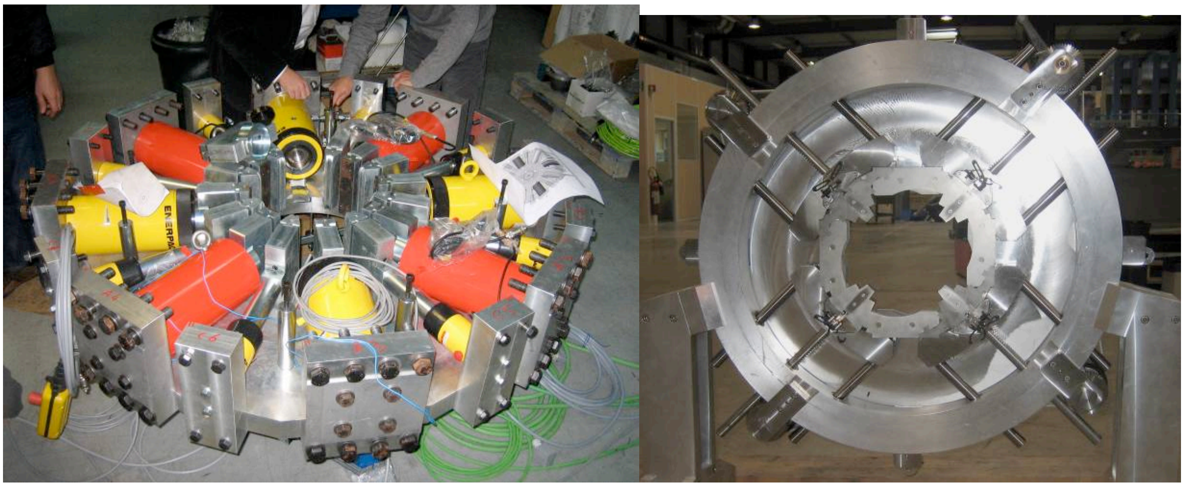

Figure 13: Left: View of the press anvils before the mounting of the cover flange. Right: Pre-assembly tooling with collar packs attached.

This collaring press has been the largest investment within the WP-6 activities. The press is now fully commissioned and the collaring procedure is validated with the assembly of the first instrumented collar pack; see report on Deliverable 6.2.1. The assembly of the first 2-m-long collared coil requires the experimental validation of the final coil size (and therefore the required shims) with the dedicated modulus press that is also fully commissioned. The final assembly assembly is planned for Summer 2011.

4. CONCLUSIONS

The final assembly of the 2-m-long model magnet cannot start before all tooling is fully commissioned. The collaring requires the press shown in Figs. 12 and 13. But before the collaring can start, the final coil size must be measured in the coil modulus press. Furthermore, the assembly must be validated with the instrumented collar packs, for which the collaring press is required. It was the design and procurement of this tooling that has caused a further delay in the assembly of the model magnet. However, all the components for the magnet models have been procured and the all the tooling has been commissioned in March 2011. Basically all investments are therefore made, and the critical path for the project has shifted from procurement to finding the resources for assembly at CEA/Saclay and at CERN. CERN and its partners are fully committed to make best use of these investments and to complete the assembly of two model magnets by autumn of 2011.

The MQXC magnet testing is an important milestone for any LHC upgrade plan and will provide the fallback solution in case that magnets with Nb3Sn superconducting technology perform below expectations.

5. REFERENCES

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