Tryout of the vacuum impregnation procedure for the ITER PF1 coil on the VPI mold made of plastic shell

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Abstract. The PF1 Coil as part of the ITER superconducting magnet system is intended for positioning and shaping of the magnetic poloidal field. The technical specification for the PF1 coil requires a full-scale simulation of the basic technological processes including vacuum pressure impregnation (VPI). Usually, a VPI mold is made of massive stainless steel walls to get the required quality of the monolithic structure of the pancake insulation by hot-curing compound. As a result, we obtain a high-cost furnace with a considerable amount of steel inside to be heated up to the specified temperature; excessive energy consumption for the furnace heating system; problems with the vacuum tightness of the VPI mold. The impregnation procedure using a VPI “plastic” mold was proposed so as to avoid the above mentioned shortcomings associated with the use of the furnace made of stainless steel.

1. Introduction

The PF1 Coil (figure 1), being part of the ITER magnet system, is designed to create the poloidal magnetic field of a specified value with the aim to control the plasma shape and position [1]. Structurally, the coil is a circular cylindrical solenoid about 9 m in outer diameter, 1 m in height and about 225 t in weight assembled of eight double pancakes.

The mechanical and operation properties of the pancakes, as well as the properties of the entire coil depend to a great extent on the quality of the monolithic structure resulting from vacuum impregnation of the composite pancake insulation by hot-curing compound. The required quality of the monolithic structure is attained, in its turn, by strict adherence to the temperature scenario specified for impregnation in compliance with stringent requirements for temperature non-uniformity of the whole coil structure.

One of the methods of fabrication of electric insulation is the VPI method using, as a rule, metal vacuum volume. The focus of this paper is on fabrication and application of alternative plastic volumes for VPI.

The calculation models and test mock-up (figure 2) of the plastic VPI mold were prepared for tryout of this vacuum impregnation technology. The analysis demonstrates that the proposed method provides the required temperature scenario for the PF1 test mock-ups and the acceptable temperature non-uniformity at a lower power consumption. The qualification sample of the PF1 coil was manufactured and tested to verify the plastic VPI mold technology to be used for the coil vacuum impregnation procedure.
2. Fabrication of fiberglass mold

Solid fiberglass mold for VPI is made of glass-cloth materials and impregnated with cold-curing compound by the infusion method. The proposed fabrication procedure for such molds includes laying of reinforcing material (glass cloth) and wrapping a sample with vacuum film, arrangement of vacuum channels and channels for resin to penetrate, pressurization of the fabricated vacuum volume, infusion of cold-curing resin into the glass cloth with subsequent polymerization at room temperature and removal of secondary materials from the surface of the finished volume. A fiberglass mold is formed around the main insulation of the coil winding and involves the following basic procedures:

- formation of the inner vacuum volume by the plastic film around the sample insulation for VPI with hot-setting compound. At the same time, this film prevents penetration into the main insulation of the sample of the cold-curing compound used for formation of the outer fiberglass mold;
- formation of the outer fiberglass mold body from glass-cloth materials for the infusion with cold-curing compound;
- formation of the vacuum volume with a plastic film wrapped around the outer fiberglass mold body;
- degassing of the inner vacuum volume to a residual pressure of about 10 Pa. In this case, the vacuum volume shell compact the main sample insulation by an air pressure of 1 kg/cm²;
- degassing of the outer vacuum volume to a residual pressure of about 10 Pa ensuring compaction of glass-cloth materials of the mold body over the outer surface of the sample;
- impregnation of glass-cloth materials of the outer mold body with cold-curing compound followed by polymerization at room temperature.

The above method was used for fabrication of the test sample of the ITER PF1 superconductive coil. The sample was made as stack of 3×3 1.6m-long bars, its cross-section with turn and main insulation is shown in figure 2. The sample was fabricated by the process accepted for manufacture of the PF1 coil [2].

Fabrication procedure of the test assembly for impregnation is shown in figures 3 - 6.
3. Calculation model

The main purpose of the thermal analysis is to set up a numerical experiment for simulation of the required mode of heat loads providing the required temperature scenario of sample impregnation. The calculation model was developed for the prototype (figure 7) and its temperature state was numerically simulated in compliance with the recommended scenario of the optimal impregnation technology (figure 8).

![Figure 7. 3DANSYS model of the test sample](image)

The calculated powers of the external heaters are shown in figure 9, the temperature distributions over the insulation at the last polymerization stage (140°C level) are given in figure 10.

![Figure 9. Power on the outer heaters](image)

![Figure 10. Temperature on the insulation](image)
On the basis of the obtained results the curves of the minimum and maximum temperature were plotted for the whole insulation layer (figure11) and for the central insulation zone, i.e. excluding local angular areas of deteriorated heating (figure12).

Figure 11. Maximum and minimum temperature on the whole insulation of the sample

Figure 12. Maximum and minimum temperature in the central zone of sample insulation

4. Impregnation procedure
Impregnation of the inner volume of the sample insulation starts after fabrication of the solid fiberglass mold in accordance with the recommended temperature scenario and calculated power of the heaters (figure 13 shows the outer layer of thermal insulation of the solid fiberglass mold). Figure 14 demonstrates the PF1 coil test mock-up after VPI, polymerization and mold dismounting.

Figure 13. Solid fiberglass mold

Figure 14. Ready-to-deliver mock-up

Conclusions
VPI parameters were calculated by the developed numerical 3D model prior to fabrication of the mock-up and its compounding. VPI process was successfully tried out.

References
[1] Magnet Design Description Document (DDD1.1-1.3), August 2004, ITER internal report
[2] Technical Specification (ANNEX B) to the procurement arrangement of the PF coils of the ITER magnet system 1.1.P3A.RF.01.