Insulating process for HT-7U central solenoid model coils

CUI Yi-Min, PAN Wan-Jiang, WU Song-Tao, WAN Yuan-Xi

(Institute of Plasma Physics, the Chinese Academy of Sciences, Hefei 230031)

Abstract The HT-7U superconducting Tokamak is a whole superconducting magnetically confined fusion device. The insulating system of its central solenoid coils is critical to its properties. In this paper the forming of the insulating system and the vacuum-pressure-impregnating (VPI) are introduced, and the whole insulating process is verified under the superconducting experiment condition.

Keywords HT-7U, CS, Vacuum pressure impregnation

CLC number TM265

1 Introduction

A Tokamak project for physics experiment device of HT-7U using superconducting coils was undertaken by Institute of Plasma Physics, the Chinese Academy of Sciences .The project is to provide scientific basis for an economical, clean and continuously operating Tokamak fusion reactor.[1] One of the most important parts of HT-7U is its magnet system, which consists of 16 magnet coils in the toroidal field (TF) system and 7 pairs of magnet coils in the poloidal field (PF) system. There are 3 pairs of central solenoid coils (CS) located symmetrically with horizontal mid-plane and central line among the 7 pairs of PF coils. Fig.1 shows the central solenoid of the HT-7U Tokamak. Now the engineering design and its first coil have been completed. The main parameters of the central solenoid coils have been presented elsewhere. [2] Insulating system is critical to magnet coil properties and more critical especially for superconducting fusion experiment devices. This paper details specifications of the HT-7U CS coil insulating system. At first, we describe the formation of the CS coil turn and layer and ground insulation. Then vacuum-pressure impregnation for the CS coil insulations is discussed. The superconducting experiments of the CS coil before and after impregnation are presented finally to testify the effectiveness of the insulating process.

2 The formation of CS coil and its insulations

The CS coil is a round-shaped structure, with 270 mm in hight and 1128 mm in outer diameter. The average length of the coil perimeter is 2560 mm. Fig.2 shows the design of the CS coil winding which consists of 140 turns of cable-in-conduit conductor (CICC) arranged in a 10 turns × 14 turns matrix. Every 10 turns is like a pancake, and there are altogether 14 pancakes. The external sectional dimensions of the conductor is 17.0 mm × 17.0 mm. Before winding, the conductor is wrapped by dry E-glass tape of 0.5 mm, forming 1 mm insulation layer between turns. The 1 mm thick pancake-to-pancake insulation is made by inserting 1 mm thick dry E-glass felt between pancakes. After the pancakes are placed well, the outside of the coil will be wrapped with a 2 mm thick dry E-glass tape to form the ground insulation. The whole coil section dimensions 185 mm × 270 mm. A part section of the CS coil is illustrated in Fig.3.

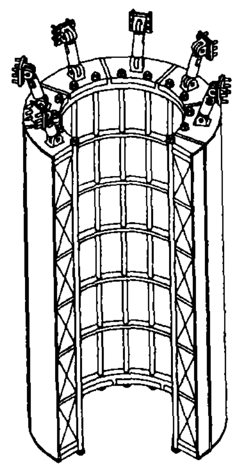

Fig.1 The HT-7U central solenoid.

Received date: 2002-06-21

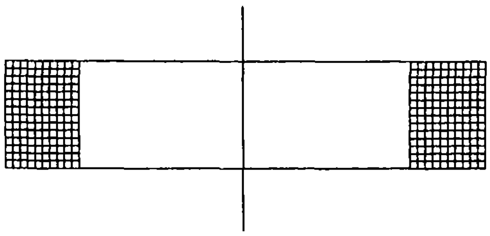

Fig.2 The TF coil winding and section view.

3 Vacuum-pressure-impregnation

In order to ensure the safety of the CS coil structure, the coils must bear mono-lithically to the imposed thermal and stresses, so all E-glass tape of the CS coils must be impregnated with epoxy by vacuum and pressure, i.e the coil will be treated by VPI (vacuum pressure impregnation). Table 1 is the resin specification for vacuum-pressure-impregnation of CS model coil. And processing parameters for CS model coil vacuum-pressure-impregnated resin is listed in Table 2. Before VPI the coil must be degassed by heating and vacuuming. After the coil insulating layer is fully impregnated with liquid epoxy, the coil temperature must be raised to gel-changed temperature of 78±3°C and the temperature must be kept for 24 h. Then the coil temperature will be raised again to the curing temperature of 130±5°C and the temperature be kept for 12 h. The whole process is described as in **3.1**.

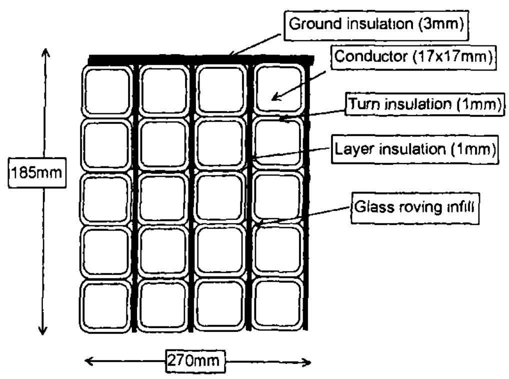

Fig.3 Illustration of a part section of CS coil.

3.1 Vacuum-pressure impregnation

1) Raise the temperature of the assembly and heat the resin to 50°C;

2) Degas the resin in vacuum while mixing;

3) Apply vacuum to coil assembly while holding at 50°C to remove air and adsorbed moisture from glass fabric of the CS coil;

4) Vacuum-pressure-impregnate the dry glass of the insulating wraps with epoxy resin through a resin inlet.

3.2 Resin cure procedures

1) Gel the resin at 78℃ for 24 h;

2) Cure the vacuum-pressure-impregnated resin with resistive heating at 130℃ for 12 h (see Table 2 for the details of the resin processing);

3) Disassemble the impregnation tools;

4) Inspect visually;

5) Machine it, if necessary, to make the outer diameter of the ground insulation within the design tolerances.

Table 1 Resin specification for vacuum-pressure-impregnation of CS model coil[3,4]

Components	Components proportion (by weight)	Commercial trade designation
DGEBF	60	YDF-175
PPGDE	40	PG-207
DETD (cure agent)	21	ETHACURE-100

Table 2 Processing parameters for CS model coil vacuum-pressure-impregnated resin

Epoxy resin	DGEBF/PPGDE/DETD
Viscosity	Lower initial viscosity and longer useable life at 50℃ are the most suitable to the impregnation (see Fig.4)
Processing temperature	50℃ (±3℃)
Gel time	78℃(±3℃) for 24 h
Working time (pot life)	>24 h at 50℃
Cure	130℃ (±5℃) for 12 h

Fig.5 and Fig.6 are photos of the unimpregnated and the impregnated CS coil, respectively. Appearance of the latter is translucent and no obvious defect is seen.

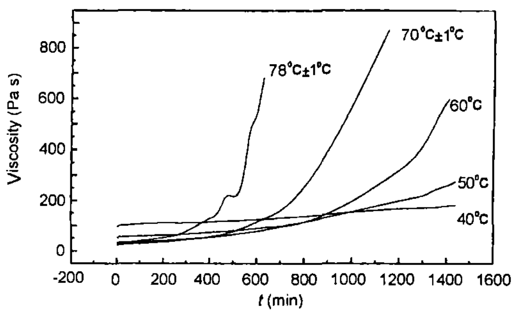

Fig.4 Viscosity-time curves for the resin at different temperatures.

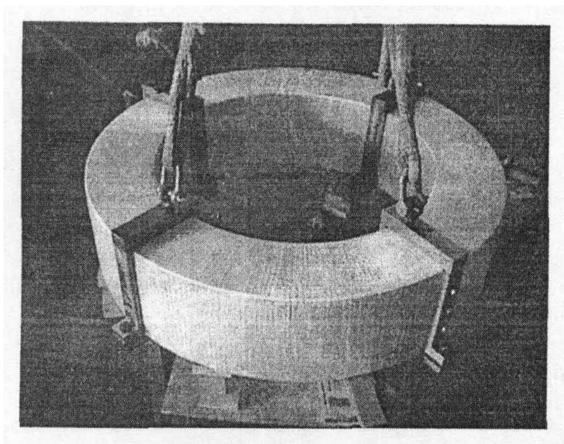

Fig.5 The unimpregnated CS coil.

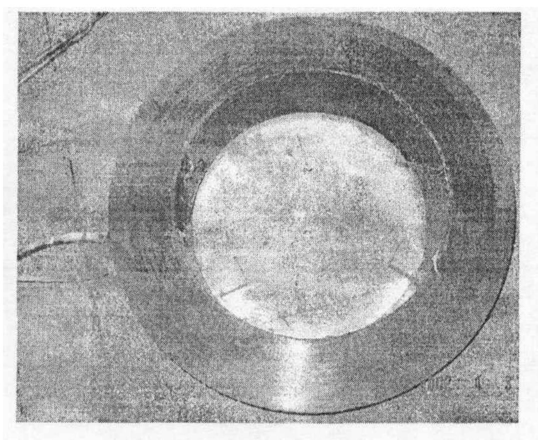

Fig.6 The impregnated CS coil.

4 Superconducting contrast experiment

High-performance superconducting magnets used in applications such as high-energy-physics and nuclear-magnetic-resonance are highly susceptible to premature quenches triggered by small heat inputs generated within the magnet winding. In modern high-performance superconducting magnets wound, conductor motion and failures of filler materials are responsible for most premature quenches. Impregnation of the magnet winding with a filler material is the technique most widely used in building high-performance magnets. The material fills the winding voids and thereby prevents Lorentz-force-induced conductor motion. Unfortunately, the technique is not completely successful because premature quenches and training behavior still persist in these impregnated magnets. The trouble is chiefly caused by failures that occur in the filler materials themselves.[5,6]The impregnation quality of the HT-7U CS coil can be tested by observing the premature quenches and training behavior in the CS coil. The experiments have been made on the CS coil before and after impregnation, and the experiment data are given in Table 3. Fig 7 is the seventh exciting current of the CS coil before impregnation, while Fig 8 is the third exciting current of the CS coil after impregnation. The design working current of the CS coil is 14 kA. After impregnation the coil can easily reach 14 kA only through twice training and no quench. Moreover, the average exciting current is 300 A/s. Comparing it with that before impregnation, we can decide that the impregnating process is successful.

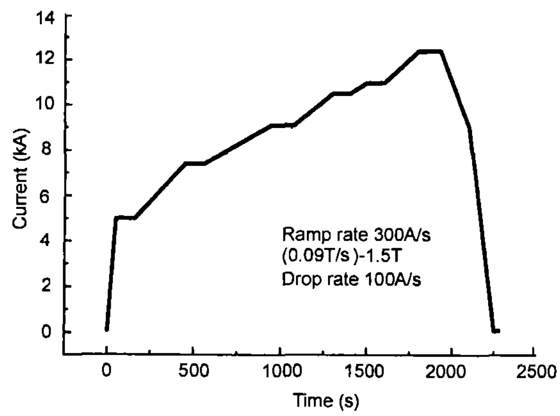

Fig.7 Seventh exciting current of the CS coil before impregnation.

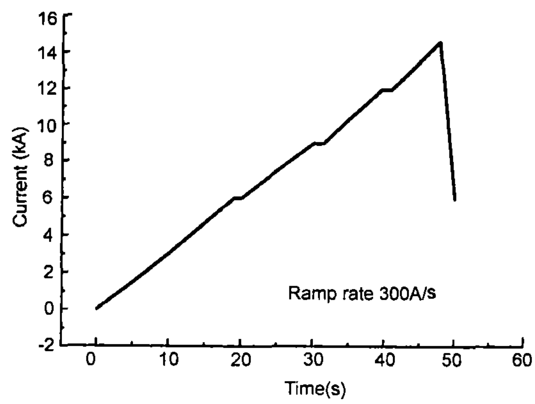

Fig.8 Third exciting current of the CS coil after impregnation.

Table 3 Superconducting experiment data of the CS coil

	Number of training	Number of quench	Average exciting current (A/s)	The largest current (kA)
Before impregnation	7	5	10 (seventh)	13.0 (seventh)
After impregnation	3	0	300 (third)	14.5(third)

5 Conclusion

The performance and reliability of the cryogenic superconducting magnet coil may critically depend on the performance of its insulating and bonding system and, therefore, special attention must be paid to the materials and techniques used. It is important that all processing parameters are fully understood. The vacuum impregnation process, if used correctly, can produce excellent results. Results of the superconducting contrast experiment have proved that the HT-7U CS coil has been successfully impregnated, and the whole insulating process is feasible.

References

1 Wu S T, Weng P D, Wan Y X *et al.* The Project of HT-7U and its Progress, MT-15, Beijing, 1997

2 Wu W Y. The Design of the Magnetic Field for HT-7U Tokamak, 2nd TCM-SSO, Fukuoka(Japan), 1999

3 Evans D, Canfer S J. A New Resin System for the Impregnation and Bonding of Large Magnet Coils, International Cryogenic Materials Conference, 1999, 243-247

4 Evans D. Techniques Available for the Vacuum Impregnation of Magnet, IPP, Hefei, 1999, 1-6

5 Fujita H, Takaghi T, Bobrov E S *et al.* IEEE Trans on Magnets, 1985, **21**(2): 380-383

6 Li B Z, Ding L R, Zhang J W. Cryog and Supercond, 1988, **16**(1): 48-51