Fusion Engineering and Design 88 (2013) 1623–1626

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Design principles for handmade electrical insulation of superconducting joints in W7-X

K. Rummel [a,*], A. John [a], Z. Sulek [b]

[a] Max Planck Institute for Plasma Physics, EURATOM Association, Wendelsteinstr. 1, 17491 Greifswald, Germany
[b] Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Radzikowskiego 152, Poland

HIGHLIGHTS

- In W-7X there are several types of handmade electrical insulation.
- In general insulation based on impregnated glass tapes and special G10 pieces.
- A proper overlapping of glass tapes turned out to be mandatory.
- Detailed qualification and training helps to minimize the failure rate.
- Visual inspection and Paschen tests after every insulation steps are important.

ARTICLE INFO

Article history:
Available online 7 March 2013

Keywords:
Electrical insulation
Paschen test
Joint
Assembly

ABSTRACT

The superconducting magnet system of the Wendelstein 7-X (W7-X) experiment consists of 50 non-planar and 20 planar coils, 121 bus bars and 14 current leads. The connection between bus bars, coils and current leads will be provided by 198 joints. The joints have to be insulated manually during the assembly of the machine in constraint positions and a tight environment. In general the insulation is based on glass tapes impregnated with epoxy resin and special G10 insulating pieces embedded in the glass tape insulation. In critical areas Kapton®-foils are embedded in the insulation. All types of insulation were qualified at mock-ups in a 1:1 model of the expected environment in W7-X. The qualification programme comprises thermal cycling between room temperature and 77 K and high voltage tests under air, under vacuum and under reduced pressure (Paschen test). The paper describes the main principles used for different types of handmade Paschen-tight insulations in W7-X and the visual and electrical tests during and after assembly.

1. Introduction

The magnet system of the Wendelstein 7-X (W7-X) experiment consists of 50 non-planar and 20 planar coils which are connected by 121 bus bars to form seven electrical circuits of ten coils each. The connection between coils and bus bars will be provided by 184 bus bar joints. The connection to the 14 current-leads will be provided by the current lead joints (CL-joint).

There are 3 different types of bus bar joints, see Fig. 1. Depending on their location in the helium cooling circuit there are joint covers with or without helium pipes. The joint housings of all types are made of stainless steel and are dismountable for possible repair. They consist of a bottom where the superconductors enter the joint and a conical cylindrical cover [1,2]. The cover is screwed inside the bottom and welded to the bottom by a lip weld. Thus the housing has several sharp edges and spanner flats at the bottom and cover end for mounting.

The bus bar joint connects not only two superconductors but also acts as connection point for the Quench Detection-wires (QD-wires). The QD-wires had to be fed through the insulation of the joints [3]. Outside of the bus bar joints they have to be connected to the QD-wires leading to the feedthroughs in the outer vessel.

The design of the CL-joint top plate is shown in Fig. 2. The CL-joint itself is mounted in a stainless steel cylinder. Inside the cylinder is vacuum, so that the cylinder needs to be insulated at its outer surface only. The insulation on the cylindrical part is premanufactured and already exists when the insulation work at W7-X starts. The bus bar enters the cylinder on the top plate. The QD-wires which are embedded in the insulation of the bus bar will be connected to an electrical feedthrough in the top plate of the cylinder. Therefore, the QD-wires have to be fed through the insulation of the bus bar.

* Corresponding author. Tel.: +49 3834 882722.
E-mail address: kerstin.rummel@ipp.mpg.de (K. Rummel).

0920-3796/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fusengdes.2013.01.017

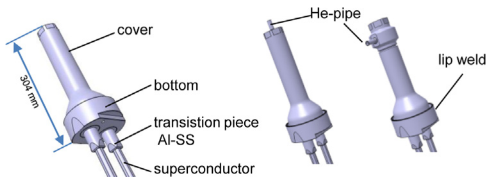

Fig. 1. Types of joint housings.

All joints and the connection of the wires have to be insulated manually during the assembly of the machine in constraint positions and a tight environment. The insulation of joints has been designed and qualified for a nominal voltage to ground of 6 kV dc and a related test voltage of 13 kV dc at Paschen conditions.

2. Sequence of insulation

2.1. Bus bar joint

The insulation starts at the superconductors and transit to the joint body to ensure the integrity of insulation. Before the joint can be mechanically mounted the end of superconductors and the transition pieces had to be insulated by insulation caps. In addition the insulation caps are used to feed the QD-wires through the insulation of the bus bars and coils near the joint. A small collar at the insulation cap provides the overlapping of the insulation of the later mounted insulation of the joint.

After installing the electrical connection of superconductors the joint housing has to be insulated. In a next step the QD-wires coming from the superconductors will be soldered to the QD-wires which run to the feedthrough in the outer vessel. Then this connection will be insulated and the connection of QD-wires has to be insulated.

2.2. CL joint

The insulation work starts when the CL-joint has been mounted. An insulation cap similar to the insulation cap of the bus bar joints is used to insulate the end of the conductor and feed two QD-wires through the insulation. After that the top plate of the cylinder will be insulated. In a next step the QD-wire feedthrough and the helium pipes on the top plate of the cylinder will be insulated. Finally the transition to the already existing insulation on the cylinder will be made.

3. Insulation layout

To ensure a high quality of on-site handmade insulations some essential aspects have to be taken into account. To avoid a breakdown in the Paschen conditions entrapped air and gaps have to be minimized and avoided, respectively. Therefore, it is important to outgas all insulation materials prior to their application and press the wet impregnated laminate during curing. Also, the existence

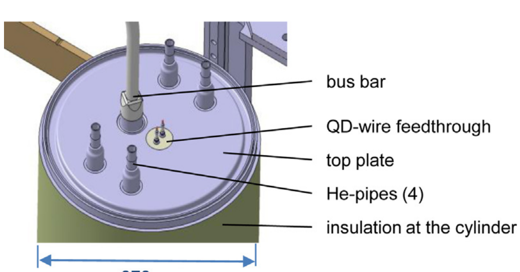

Fig. 2. Top plate of the CL-joint.

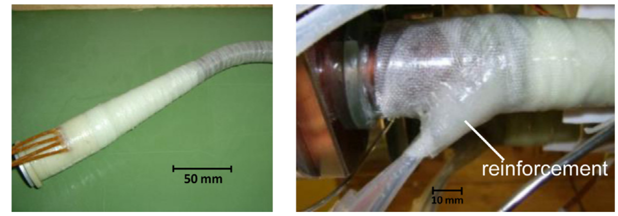

Fig. 3. Left: insulation cap without reinforcement. Right: with reinforcement.

of metallic pieces (e.g. QD-wires) on floating potentials has to be avoided.

All parts of insulations had to be overlapped. That means G10 pieces which consist of parts should have some steps or cones in the section area. Adhesive gaps are weak points of insulation and have to be carefully filled with resin. It is recommended to reinforce these glued insulation pieces by an additional glass fibre wrap or cover the adhesive area with pressed glass fibre tapes. A layer of Kapton® foil as first barrier underneath each adhesive gap helps to increase the dielectric strength.

To achieve the required high glass content of more than 60% the wet laminate has to be tightly pressed during curing. The cold curing epoxy resin system used is a mixture of the resin Araldit D and the hardener Aradur HY956. The glass fibre tapes are made of E-glass with a width between 20 and 50 mm and a thickness of 0.2 mm. The area weight of the tapes is 225 g/m^2. The thickness of the Kapton® foil is 0.05 mm.

Finally all insulation parts will be covered with semi-conductive paint to ensure the discharge of surface potential to ground.

The proper function of the insulation will be tested after every insulation step and on-site in a Paschen test in local chambers.

Details of the insulation work will be given in the following chapters.

3.1. Bus bar joint – insulation of superconductor near the joint and wire feedthrough

The insulation caps, shown in Fig. 3, will be assembled at the transition piece at the terminal ends of coils and bus bars during the preparation process outside the machine. The caps consist of two half shells of preformed G10 which will be glued together on the transition piece with a sheet of Kapton® foil underneath the adhesive gap. Additional six half overlapping layers of wet impregnated glass fibre tape are directly wrapped around the cap.

Four Kapton® insulated QD-wires will be fed through 4 holes in the cap [3]. These wires are embedded in the insulation cap with glass fibre reinforced epoxy resin, see Fig. 3, left.

This kind of insulation is very robust. Neither at qualification samples nor at the 280 assembled insulation caps at W7-X failures occurred.

During the assembly of joints on-site in the machine a special problem occurred. Some cracks in the Kapton® insulation of the QD-wires itself outside the insulation caps were observed. It was found that the reason for these cracks is the contamination of the QD-wire surface with resin. So the wires become very stiff in this area and while bending their insulation cracks. Therefore, to reinforce the wires and avoid overbending hoses of polyethylene (PE) were put over the wires outside the cap and embedded in a reinforced resin with an additional glass tape wrap (Fig. 3, right). This reinforcement has no impact on the electrical insulation itself and serves only as mechanical protection. This reinforcement was carried out at all 280 insulation caps after the Paschen test of the insulation caps.