Investigation of thermal insulation for static cryostats of HTSC devices**

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The experimental investigation of high temperature superconductor (HTSC) electrotechnical devices may be substantially simplified using multilayer thermal insulation. Test results are reported for the foamed rubber K-FLEX and the aerogel JODA-C, applied as external thermal insulation of static cryostats intended for cryogenic devices, in particular HTSC alternators.

Keywords: aerogel, foamed rubber, HTSC electrotechnical devices

1. Introduction

At present thermal insulation for cryogenic electrotechnical devices comprises two main groups: screen-vacuum and multilayer insulation. Static cryostats may be either metallic or nonmetallic. If the cooled device generates an external alternating magnetic field, which may cause eddy-current loss in the inner shell of a metallic cryostat facing the cryogenic coolant, nonmetallic cryostats are preferable. We have vast experience with the application of nonmetallic cryostats. We used them in the first stage of our experiments with high temperature superconductor (HTSC) devices, cooled by liquid nitrogen (LN_2). Plastic cryostats with vacuum insulation cannot keep their vacuum for a long time and need practically continuous pumping out. Insofar as we have demonstrated the absence of external alternating magnetic fields in electrical machines with an axial magnetic flux, we started to apply thermal insulation for the outer frame of model disc alternators.

2. Experimental setup

Foamed rubber K-FLEX sheets were chosen for a set of preliminary investigations. The principal advantages of this thermal insulation are listed by the manufacturer, L'ISOLANTE

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K-FLEX GmbH.[1] The range of its application lies between –200 and +90 °C. Its thermal conductivity slightly depends on the temperature and is about 0.04 W m^{-1} K^{-1}. It is environmentally friendly and differs from competing products by superior fire safety and low toxicity.

Our tests covered two main aspects: determination of the optimal thickness of the thermal insulation with LN_2 and evaluation of any K-FLEX aging process in LN_2.

To investigate the dynamics of cold penetration and of the temperature on the outer thermal insulation (K-FLEX) surface of a static cryostat a special model cylinder manufactured from stainless steel was developed.[2] The side and bottom outer surfaces were polished and covered with thermal insulation layers (the K-FLEX sheet thickness was 18 mm) fixed by a special glue (Fig. 1). The cylinder is filled with LN_2 via a foam plug. The dependence of the rate of LN_2 evaporation on the thickness of thermal insulation was investigated as well.

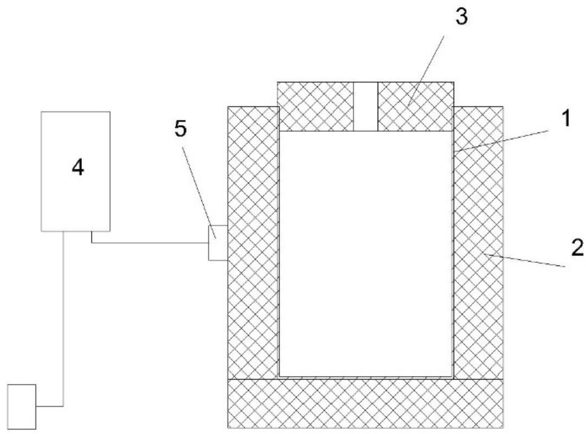


Figure 1. Schematic diagram of the model testing rig: 1, metal cylinder; 2, outer thermal insulation; 3, foam plug; 4, digital thermometer; 5, thermocouples.

During the tests the ambient temperature was equal to 25 °C and the temperature of the coolant was approximately –196 °C.

3. Results from K-FLEX

The data presented in Fig. 2 show that two layers of the thermal insulation are a minimum requirement for the static cryostat of an electrical machine during long-term experiments with LN_2 cooling. The rate of LN_2 evaporation (Fig. 3) confirmed that two layers are sufficient. The curve for 3 layers is practically the same as the one obtained with 2 layers (total thickness 36 mm).

The behaviour of K-FLEX during thermocycling was investigated as follows. A two-layer sample was immersed in LN_2, cooled down in it, and then warmed up to ambient temperature

[1] http://www.kflex.com/en/#

[2] Eu.N. Andreev et al., Application of materials on the basis of foamed rubber as a thermal insulation of high-temperature superconducting devices. *Intl Conf. on Electromechanics and Robotics "Zavalishin's Readings"*, 8–12 April 2013, St Petersburg State University of Aerospace Instrumentation, pp. 1–6.

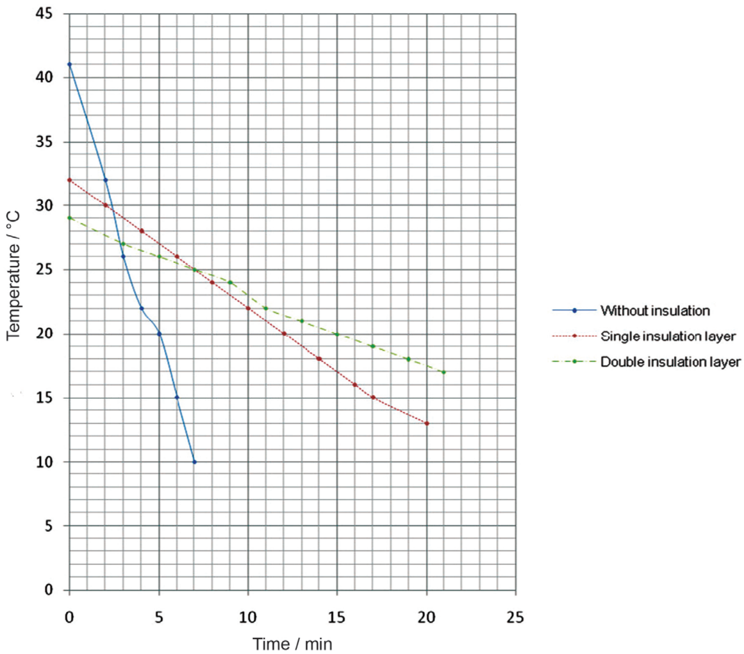


Figure 2. Variation of the temperature on the external surface of the cryostat. Insulation provided by layer(s) of K_FLEX.

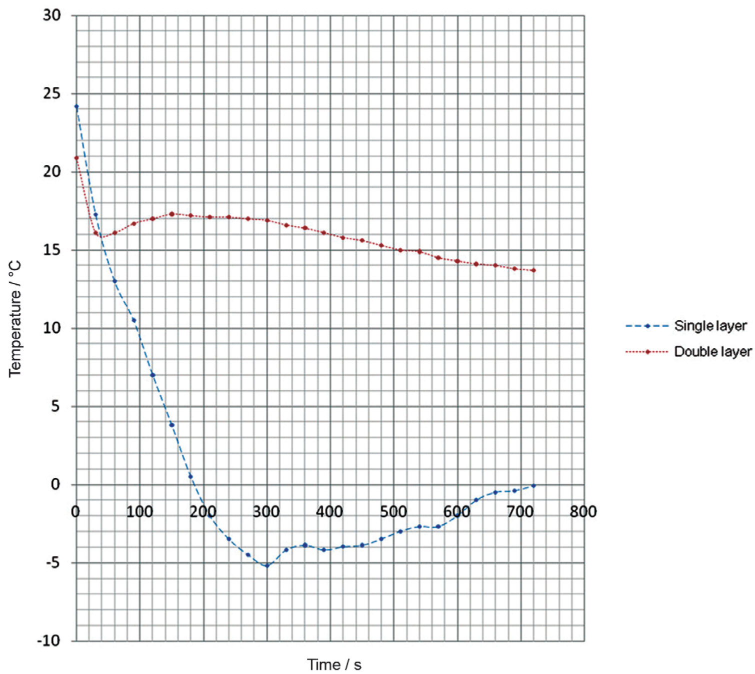
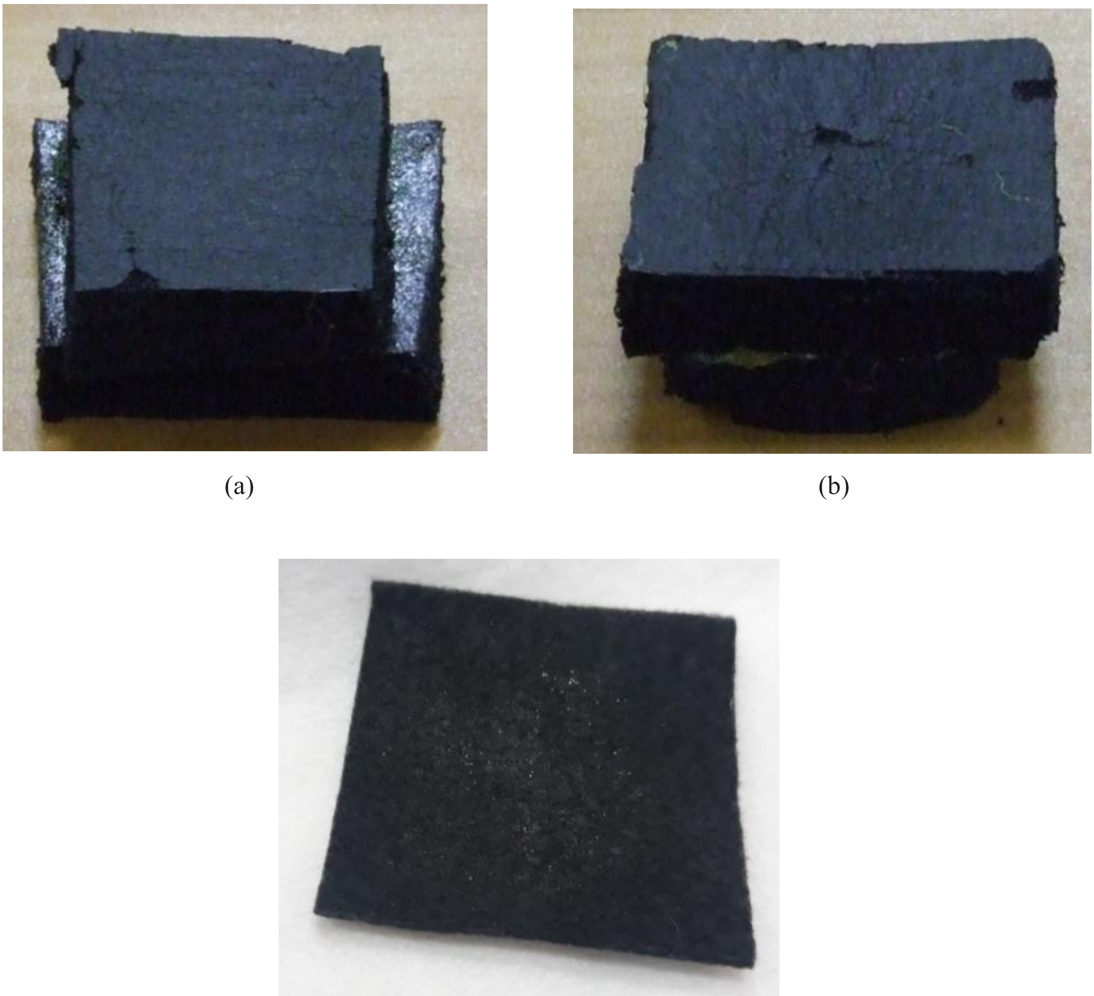


Figure 3. Variation of temperature on the external surface of the cryostat with a single or double layer of K-FLEX insulation.

(20 °C). Results are shown in Fig. 4. The two-layer sample before experiments is shown in Fig. 4a. After the 1st thermocycle, cracks appeared on the sample surface. It became less elastic and showed a tendency to crumble. After the 3rd thermocycle a dent appeared in the centre of the sample (Fig. 4b). A total of 10 thermocycles were applied, but after the 3rd one no further visible changes appeared.



(a) (b) (c)

Figure 4. Results from thermocycling: (a) K-FLEX prior to thermocycling; (b) K-FLEX after 3 thermocycles; (c) JODA-C after 3 thermocycles.

The elasticity of the sample improves with the time, but not to the initial level. The material stays more rigid. It is necessary to be accurate during experiments with liquid nitrogen not to spoil the outer thermal insulation of the static cryostat of the device.

Experiments with a rotating electrical machine showed additional advantages of K-FLEX: it provides good acoustic insulation and damps the alternator vibrations.[3] A general view of the model HTSC alternator with a metallic static cryostat covered with sheets of K-FLEX is shown in Fig. 5.

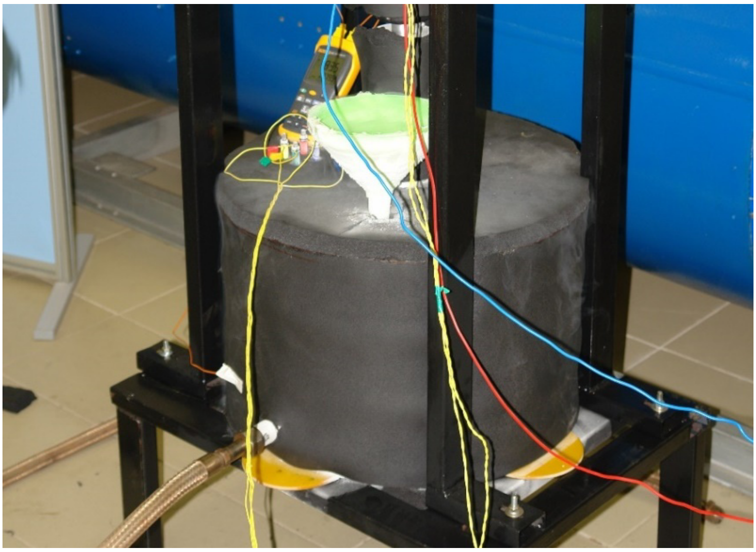


Figure 5. An HTSC alternator with a metal static cryostat covered with sheets of K-FLEX.

4. Other products

Thermal insulation JODA-C is a carbon fibre-based aerogel supplied in sheets.[4] Its thermal conductivity at ambient temperatures is around 0.016 W m^{-1} K^{-1}, which is almost 3 times less than that of K-FLEX. This aerogel possesses hydrophobic properties and its vapour permeability is about 99.8%. The material is environmentally friendly and nonflammable. Its behaviour in LN_2 after 3 thermocycles is shown in Fig. 4c.

Cryogel is constituted from a cloth of glass fibres saturated by aerogel particles and covered with an aluminum foil.[5] It is considered to be a cryogenic thermal insulation of the new generation and provides high-quality protection of cryogenic equipment and a long failure-free functioning of cryogenic equipment. It has extremely low thermal conductivity (Fig. 6) and can operate at LH_2 temperature.

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[3] L. Chubraeva and S. Timofeyev, Project of autonomous power plant with high-temperature superconductive devices. *Intl Multi-Conf. on Industrial Engineering and Modern Technologies (FarEastCon),* 3–4 October 2018. Far-Eastern Federal University, Vladivostok, pp. 1–5.

[4] https://www.joda-tech.com

[5] https://www.aerogel.com/products-and-solutions/cryogel-z/

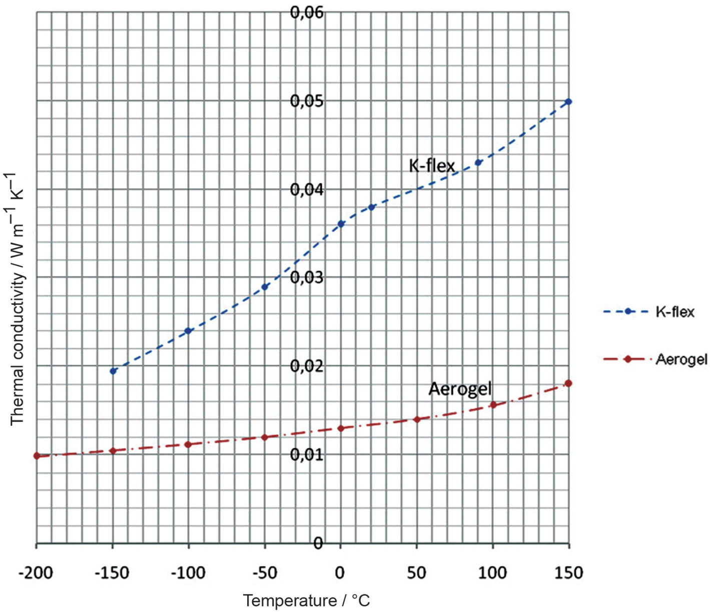

Figure 6. Thermal conductivity of K-FLEX and Cryogel (labeled Aerogel).

5. Conclusions

1. The K-FLEX thermal insulation is applicable to static cryostats of cryogenic devices, operating with LN_2. It permits the design to be simplified and the expenses to be decreased for HTSC model investigations.

2. New thermal insulation products like Cryogel have more favourable properties for cryogenic devices, like lower thermal conductivity and better mechanical characteristics.