

PAPER • OPEN ACCESS

## Features of thermal ageing of cables with different type of insulation

To cite this article: A B Vlasov and S V Vlasova 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012132

View the [article online](#) for updates and enhancements.



**IOP | ebooks™**

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

# Features of thermal ageing of cables with different type of insulation

A B Vlasov and S V Vlasova

Ship Electrical Equipment Department, Murmansk State Technical University, Sportivnaya, Murmansk, 183010, Russian Federation

E-mail: vlasovab@mstu.edu.ru

**Abstract.** A wide range of temperature and duration of cable routes operation requires the development of objective methods for assessing the properties of cable insulation. While working, preparing and repairing cable routes, it is important to use express methods to determine the technical condition of insulation, to search for diagnostic parameters indicating the process of crack formation. An ongoing monitoring of cable insulation with standard devices controlling electrical resistance and leakage currents is not sufficiently effective for evaluating the performance and predicting the properties of cable insulation. The study is aimed at further testing of the technique by analysing the properties of materials used in cable engineering, as well as comparing the results obtained by various devices manufactured by national and foreign companies. Tests were carried out to assess the quality of insulation based on the monitoring of hardness of the hose insulation and the conductor insulation of KNR and KNREk cables. In the KNREk type cables, the core insulation is also made of the RTI type rubber, but the hose insulation is created on the basis of a material from polyvinyl chloride compound. The method of assessing the quality of insulation and assessing the degree of ageing of cable material is implemented by measuring the hardness of insulation material using the Shore method using portable hardness testers of the following types: TH-200, NOVOTEST TS D-A (TS D-D) up to 100 *HSA* (*HSD*). It is shown that the proposed technique makes it possible to identify objective statistical parameters of the material hardness and to diagnose the quality of insulation in operation without dismantling cable routes. The hardness parameters of hose insulation from polyvinyl chloride compound can be controlled by TS D-D devices. The heat resistance of hose insulation of the KNREk type cables is higher than that of the cables of the KNR type, which creates opportunities for their longer operation at high temperatures.

## 1. Introduction

The variety of range of cable insulation, the wide temperature range of cable routes, the duration of operation of vessels requires the development of objective methods for assessing the properties of cable insulation. An ongoing monitoring of cable insulation with standard devices controlling electrical resistance and leakage currents is not sufficiently effective for evaluating the performance and predicting the properties of cable insulation.

During operation, when preparing and repairing cable routes, it is important to use express methods to determine the technical condition of insulation, to search for diagnostic parameters indicating the process of crack formation during a long period of operation in a wide temperature range [1].

The ageing of insulation over time is accompanied by a change in its physical and mechanical properties, the analysis of which shows [2,3] that the parameters characterizing the elastic properties



of the material are the most promising for controlling. The papers [4,5] propose a method for assessing the quality of insulation based on the control of hardness of the hose insulation and the conductor insulation. On the basis of the developed method, it is possible to conduct operational monitoring of the current state of insulation aged during long-term operation.

The study is aimed at further testing of the technique by analysing the properties of materials used in cable engineering, as well as comparing the results obtained by various devices manufactured by national and foreign companies.

## 2. Materials and testing methods

In industry, including on ships, along with KNR (ship cable with copper conductors with rubber insulation, in sheath from oil-resistant rubber, flame retardant), NRSHM (ship cable with copper conductors, with rubber insulation, in sheath from oil-resistant rubber, flame retardant), KNRE (ship cable with copper conductors, with rubber insulation, in sheath from oil-resistant rubber, flame retardant, screened by tinned copper wires) cables and others, cable routes with cables of the KNREk (for example, GOST 7866.2-76) (ship cable with copper conductors, with rubber insulation, screen of copper wires, positioned between two sheaths from PVC compound), KNRk (ship cable with copper conductors, with rubber insulation, in sheath from PVC-compound), KNRPk (ship cable with copper conductors, with rubber insulation, with inner and outer sheaths from PVC-compound, with mesh guards from galvanized steel wires), KNRTEk (ship cable with copper conductors, with rubber insulation, with inner and outer sheaths from PVC-compound, with screen of copper wires or foils), KNRETEk (ship cable with copper conductors, with rubber insulation, with foil film, with inner and outer sheaths from PVC-compound, with screen from tinned wire) types and others are widely used.

Cables of the KNR type (flame retardant cable with chloroprene insulation) are characterized by hose rubber insulation of the RSHN type, and insulation of the conductor is made from the RTI type rubber.

In the KNREk type cables, the core insulation is also made of the RTI type rubber, but the hose insulation is created on the basis of a material from polyvinyl chloride compound, for example, I40-13A, OM-40, etc.

Despite the prevalence of such cables, their service life is not defined, since it strongly depends on the operating temperature. For example, service life of cables with hose rubber insulation in continuous operation at above 65 °C is not more than 6 years, and in some premises, for example, in boiler rooms, at the outlet manifolds, contacts of lamps, junction boxes and similar places, cracks on the cable surface start to appear after 2-3 years of operation. It is believed that the service life of KNREk cables is 25 years at ambient temperatures not exceeding 45 °C.

Common industrial cables of the KNR and KNREk type, subjected to accelerated ageing at temperatures of 110-130 °C, were chosen as test objects. In order to assess the effect of temperature and ageing time on the hardness of the hose insulation and the conductor insulation, cable sections were placed in a thermostat and kept at a fixed temperature for a long time. A grid of visible cracks on the insulation served as an objective criterion for the loss of insulating properties.

Considering that conductor insulation material in KNR and KNREk cables is almost identical, the main attention in the test is paid to comparing the properties of the material of the hose insulation, RSHN rubber and PVC compound, respectively.

The method of assessing the quality of insulation and assessing the degree of ageing of cable material is implemented by measuring the hardness  $H_i$  ( $HSA/HSD$ ) of individual elements of the insulation material using the Shore method. The hardness parameters were measured by portable hardness testers of the types T-200, NOVOTEST TS D-A (TS, D-D) up to 100  $NSA$  ( $HSD$ ). The TS TS-A device is used for softer materials, including rubber (elastomers), TS D-D – for more rigid dielectrics.

The advantage of this technique is the ability to determine the hardness of cables insulation directly during operation, including under voltage, without dismantling the route.

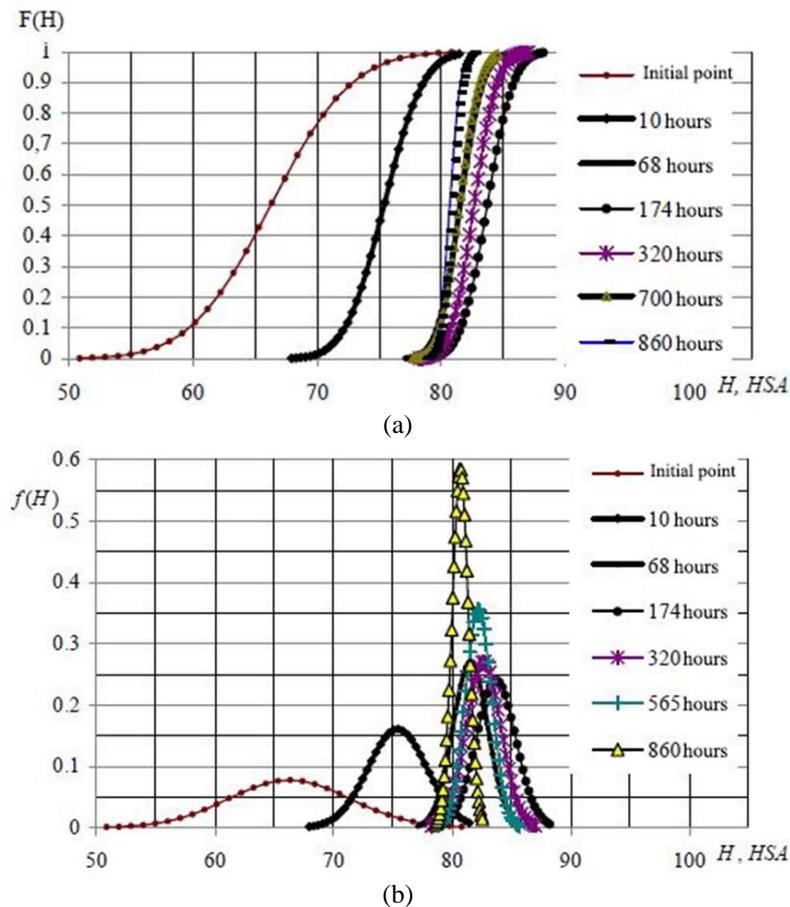
During the tests, the hardness of the hose insulation and the conductor insulation were studied based on the analysis of data from a sample of  $n = 25-30$  changes. During the tests, the  $H_i$  values of hardness of the analysed sample are repeatedly measured, so that each  $H_i$  value is a random variable that takes one of the possible hardness values within a certain range from  $H_{\min}$  to  $H_{\max}$  as a result of the tests. The set of sample values, as values of a random variable, form a statistical series. Using mathematical data processing, the following values were calculated: the average value –  $H$ , the absolute error –  $\Delta H$ , taking into account the Student's coefficient –  $t_n$  (confidence probability  $P = 0.95$ ). Assuming that the experimental data are described by normal distribution law, the distribution function  $F(x)$  and the distribution density  $f(x)$  were calculated using standard methods. The distribution function  $F(H)$ , which determines the probability of occurrence of a random variable, takes values from 0 to 1 (integral function); the distribution density, equal to  $f(H) = dF(H)/dH$ , shows the probability of a random variable falling into a given interval and characterizes which random variable values are most probable.

### 3. Results and discussion

The developed technique is based on the assessment of insulation quality according to the diagnostic parameter – hardness of the material, the limiting value of which is reached after the expiration of the service life. In particular, the limiting values of rubber insulation hardness of a KNR cable are the values of  $H_{c.i.} \approx 94-95$  HSA, in which the surface of the insulation is covered with cracks and the cable loses its performance [4,5]. It is known [1-3] that during operation, due to chemical reactions, the cable loses its elasticity, flexibility, and becomes rigid. Initially, a mesh of small cracks appears on its sheath and insulation, and then, finally, cracks, opening up the access of moist air, contaminants up to the metal conductor. In the absence of pollution and in dry air, the electrical resistance of a cable with cracks in the insulation may remain relatively high, but it drops sharply in a wet or corrosive environment, which is typical of the conditions of operation of cable routes on sea vessels.

The figure 1 shows the calculated distribution function  $F(x)$  and the distribution density  $f(x)$ , obtained using a TH-200 device,  $H_{c.i.}$  hardness of the KNR cable conductor insulation ( $3 \times 2.5$  mm<sup>2</sup>) during prolonged ageing at a temperature of 100 °C. In the process of testing it is shown that the average value of  $H_{h.i.}$  hardness of conductor insulation increases from 67 HSA to 84 HSA within 800 h; while 40-50% of conductor insulation lose their rigidity and crack with a slight deformation.

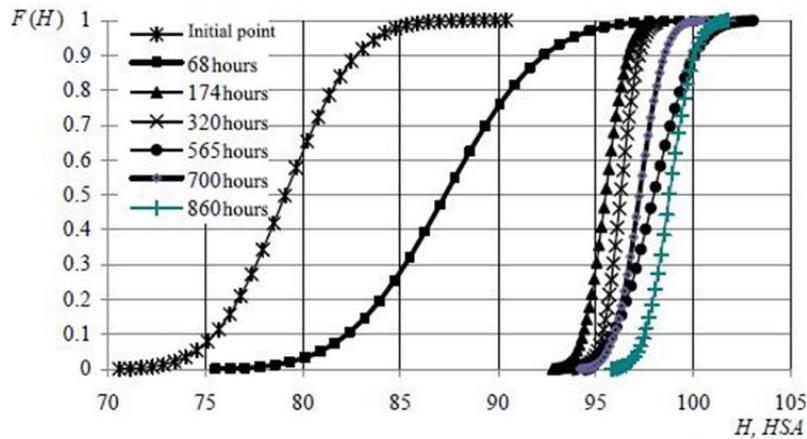
The figure 2 shows the test results obtained by the TH-200 device of hose insulation hardness  $H_{h.i.}$  of KNR cable ( $3 \times 2.5$  mm<sup>2</sup>) during ageing at a temperature of 100 °C: in the process of ageing, the average hardness value  $H_{h.i.}$  of conductor insulation increases from 78 HSA to 97 HSA for 800 h.



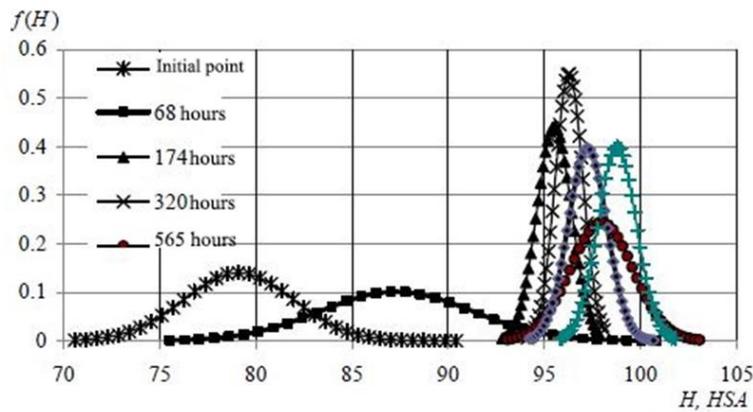
**Figure 1.** Change in the functions  $F(H)$  and  $f(H)$  of the KNR cable conductor insulation during the ageing process at 100 °C (the TH-200 device).

The figure 3 shows the dependence characterizing the change in the hardness of the hose insulation  $H_{h.i.}$  at different values of the distribution function  $F(H)$ .

It can be seen (Figure 2, 3) that after 200 h of aging at a temperature  $T = 100$  °C, the average hardness value of the hose insulation –  $H_{h.i.}$  – increases from 78 HSA to 95 HSA, after which it remains relatively constant. When ageing more than 600 hours at  $T = 100$  °C, the hardness of the hose insulation –  $H_{h.i.max}$  – increases to 100 HSA ( $F = 0.95$ ), which is accompanied by the appearance of the first cracks on the surface of cable hose insulation.

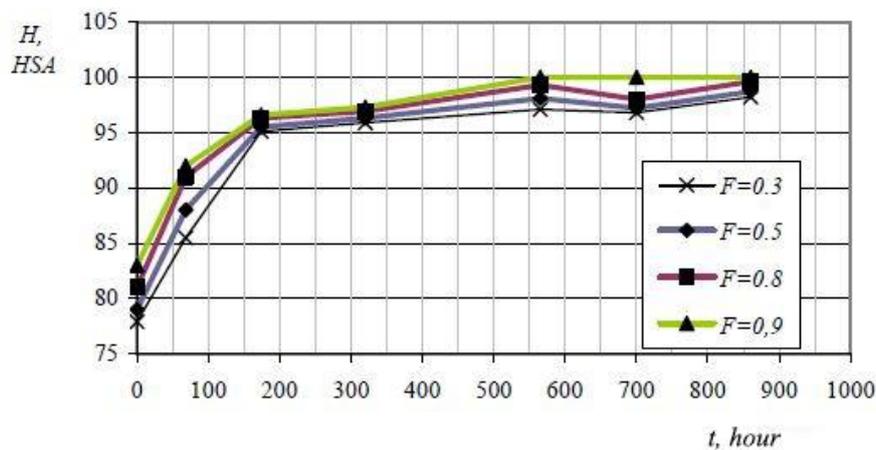


(a)



(b)

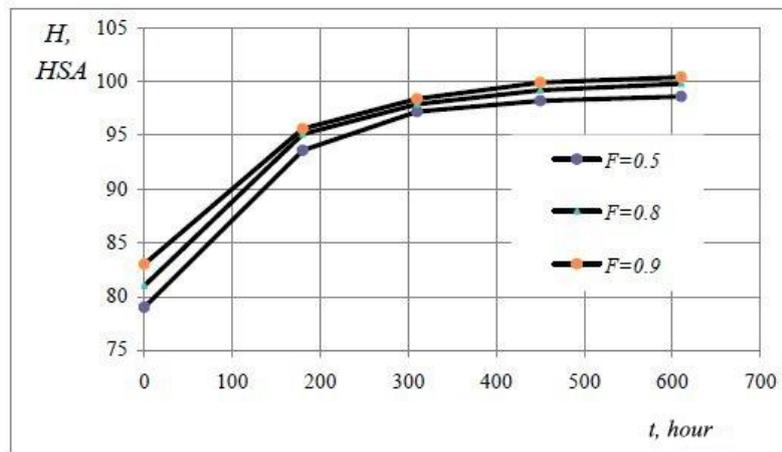
**Figure 2.** Change in the functions  $F(H)$  and  $f(H)$  of the KNR conductor hose insulation during the ageing process at 100 °C (the TH-200 device).



**Figure 3.** Dependence of the change in hardness of the KNR cable hose insulation  $H_{h.i.}$  at different values of the distribution function  $F(H)$  (ageing temperature of 100 °C).

An increase of ageing temperature up to 130 °C leads to accelerated ageing (Figure 4), so that the critical values of hose insulation hardness –  $H_{h.i.}$  – are reached within 300-350 h.

b)

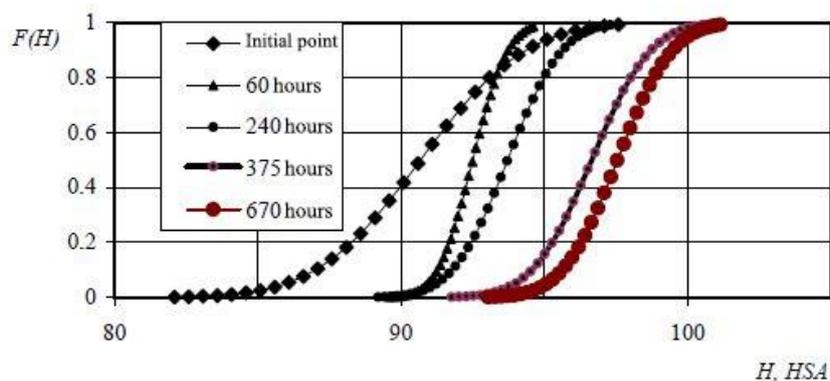


**Figure 4.** Dependence of the change in hardness of the KNR cable hose insulation  $H_{h.i.}$  at different values of the distribution function  $F(H)$  (ageing temperature of 130 °C).

The tests show that insulation of KNREk cables is more heat resistant than insulation of KNR cables. Figure 5 shows the results of testing the KNREk cable hardness ( $2 \times 2.5$ ) with ageing up to 700 h at a temperature of 130 °C. When ageing at elevated temperatures, the hardness of the hose insulation increases above  $H = 100-105$  HSA and higher, but cracks on the surface of the insulation from polyvinyl chloride compound are not observed even at ageing during more than 700-800 h.

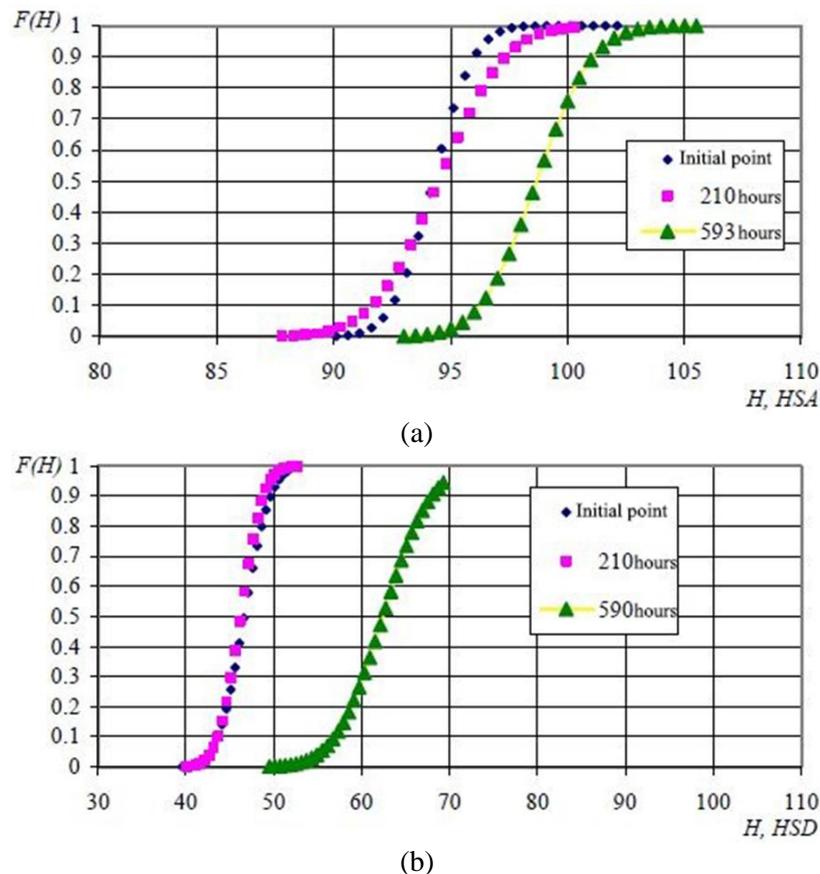
The increase in the hardness of the KNREk cable insulation, created on the basis of polyvinyl chloride compound, to values higher than 100 HSA, makes it difficult to estimate this parameter with a TH-200 or a TS D-A device (in HSA units). That is why it is relevant to compare the results obtained with the help of various devices, including NOVOTEST TS D-A (in HSA units) and TS D-D (in HSD units).

The figure 6 shows the results of testing the hardness of the KNREk cable hose insulation ( $2 \times 2.5$ ) during thermal process using NOVOTEST TS D-A and (a) TS D-D (b) devices.



**Figure 5.** Change in the hardness distribution function of the KNREk cable hose insulation during the ageing process at 100 °C (the TH-200 device).

It can be seen that measurements obtained by the TS D-A device are identical to those of the TH-200 device. The results of measurements of the hardness of the hose insulation and the conductor insulation using the TS D-D device have lower values. For example, for the original KNREk cable, the average hardness of the hose insulation –  $H_{h.i.}$  – is 94 HSA and 46 HSD, respectively.



**Figure 6.** Results of testing the hardness of the KNREk cable hose insulation using TS D-A and (a) TS D-D (b) devices.

When the hardness of the hose insulation exceeds the value of 100 HSA while using the TH-200 and TS D-A devices, it does not allow to perform correct testing. The results of tests show that the ageing control can be performed by using the TS D-D device in the temperature range and test time under study.

Rapid tests of cable insulation hardness make it possible to give expert assessments of the performance of cable routes without dismantling them. The probable service life of cable insulation can be determined by analysing the results of accelerated tests at different temperatures.

#### 4. Conclusion

1. The presented results of testing the hardness of the hose insulation and the conductor insulation show that the proposed method makes it possible to reveal objective statistical parameters of the material hardness and to diagnose the quality of insulation in operation without dismantling cable routes.

2. The hardness parameters of the hose insulation from polyvinyl chloride compound can be controlled by TS D-D devices.

3. The heat resistance of hose insulation of the KNREk type cables is higher than that of the cables of the KNR type, which creates opportunities for their longer operation at high temperatures.

#### Acknowledgments

The work has been carried out within the state assignment of the Russian Federation Ministry of Education and Science, project No. ГП АААА-А17-117041210284-1).

**References**

- [1] Hampton N, Rick Hartlein R, Lennartsson N, Orton H 2007 Long-life XLPE insulated power cables *Jicable* **5** 1–5
- [2] Malyshev L A 2002 *Fundamentals of theory, methods and means of technical diagnostics of ship cables* (St.Peterburg: Russian Maritime Register of Shipping) 273 p
- [3] Akberdin A M, Pavlova Z Kh 2006 Assessment of the technical state of pumping station power cables in use *Transport and Storage of Oil and Gas* **6(2)** 99-104
- [4] Vlasov A B, Muhalev V A RU Patent No. 109394/07 (5 October 2017)
- [5] Vlasov A B, Vlasova S V, Muhalev V A 2016 Analysis of changes in the hardness of cable insulation during accelerated ageing at elevated temperatures *Sudostroenie* **3** 31-33