Comparison of diagnostic methods for thermal aging of shipboard cable

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Abstract. This paper proposes a comparison of two methods for diagnosing the insulation condition of ship power cables that are subject to accelerated aging at elevated temperatures. Earlier, an express methodology was presented for checking ship cables by measuring the hardness of insulation of conductors and the hose sheath with a device according to the Shore method, which makes it possible to estimate the service life of cable routes without dismantling them. The methodology was tested on fishing vessels and was taken into account by the Russian Maritime Register of Shipping. However, any applied diagnostic methods are not without faults due to interference and errors, and therefore cannot provide a reliable control result. To increase the reliability of the audit of various electrical equipment and ship cables, it is advisable to control other parameters characterizing the technical condition of the facility. One of these parameters is the dielectric loss tangent (\( \tan \delta \)), which can be measured with the Tangens 2000 instrument. The article presents the results of measuring the insulation hardness and loss tangent during thermal aging of a ship cable KNRE 2x1, and a comparison of two methods for assessing the condition and service life of a cable.

1. Introduction
Marine cables used on marine vessels have a certain service life. Depending on the temperature and humidity in the room, the magnitude of the load, this period may vary. Moreover, traditionally, the issue of replacing a specific ship cable is resolved only in the event of an accident.

The main reason for the failure of the ship's cable is a violation of the integrity of the insulation, which is caused by a decrease in the elasticity of rubber due to aging. There is a technique for the diagnosis of ship cables by measuring the hardness of the sheath and cable cores [4].

For cable diagnostics, a Shore hardness tester is used. A hardness meter with a scale from 0 HSA to 100 HSA is used to determine the hardness of conductors that are less susceptible to hardening during the service life, a device with a scale of 0 HSD to 100 HSD is used to measure the hardness of the cable sheath.

Due to the specificity of the hardness measurement process, the final result is obtained after computer processing of a series of measurements using Excel. Using the normal distribution function, the graphs \( F(x) \) – the distribution function and \( f(x) \) – probability density function are plotted.

In [2] a technique for express diagnostics of ship cables is presented. Accelerated aging of the cable is carried out by heating it in a furnace at temperatures of 100-130 °C.

As a result of the tests, the authors of the method concluded that with a hardness of more than 90 HSA cracks may appear on the cable, which may indicate an emergency defect.
In the present work, it was proposed to similarly repeat tests of ship cables at elevated temperatures, making measurements of the hardness of cores and hose insulation.

To increase the reliability of the audit of ship cables, the dielectric loss tangent ($\tan\delta$) and insulation capacitance ($C_x$) were measured.

2. Determination of hardness of shipboard cable subject to thermal aging.

To conduct the test, we took a ship cable KNRE 2x1, which was placed in a thermostat with a temperature of 130 °C. Further, with an irregular frequency, the cable was removed. After cooling to room temperature, we measured the hardness of the cores and hose insulation.

Figures 1 and 2 show graphs of the probability function and density distribution of the hardness of the cable sheath, measured by the device according to the Shore method with the HSA scale.

![Figure 1](image1.png)

**Figure 1.** The distribution function of the hardness of the hose insulation at various points during the cable test

![Figure 2](image2.png)

**Figure 2.** The function of the density distribution of the hardness of the hose insulation at various points in the cable test

After 6 days of testing the cable at a temperature of 130 °C, the hardness of the rubber sheath reached 95 HSA (Fig. 3). With this value of hardness, the hose insulation cracked in case of bending.
The intersection of the horizontal red line with the graph indicates the point in time when the hardness value becomes emergency.

![Figure 3](image)

**Figure 3.** The change of hardness of the hose insulation over time

As can be seen from the graph, the hardness indications of the cable sheath reached the limit of the HSA scale by 300 hours of heating. For further monitoring of hardness, it is advisable to use a hardness measuring instrument with an HSD scale. The measurement data are presented in Figure 4.

![Figure 4](image)

**Figure 4.** Hose insulation hardness distribution density as measured by HSD

It can be seen that up to 63 hours of observations, the insulation hardness varies insignificantly, however, the following measurements indicate an abrupt increase in hardness.

To control the change in the hardness of the wires, part of the cable was exposed, which led to an increase in the influence of the air, and therefore increased mass loss, due to more intensive evaporation of plasticizers. Data for one of the cable cores is shown in Figure 5.
By the time of 156 hours, cracks appeared on the core, indicating damage to the cable, the core hardness was 67 HSA.

3. Measurement of the dielectric loss tangent (tan\(\delta\)) of the KNRE cable

The dielectric loss tangent (Figure 6) does not depend on the size of the insulating structure, since when they change, the active and reactive components of the current flowing through the dielectric proportionally change (1) [3].

\[
\tan\delta = \frac{P_a}{Q} = \frac{I_c U_c}{I_a U_a} = \frac{I_a}{I_c}
\]

(1)

where \(\tan\delta = \frac{\pi}{2\cdot\varphi}\) is the dielectric loss angle, usually the value is expressed as a percentage; \(P_a, Q\) are the active and reactive powers.

The Tangens 2000 insulation meter is a \(\tan\delta\) and \(C\) meter of various electrical insulation materials according to direct and inverse measurement schemes. The meter also allows you to measure the voltage at the test object.

The insulation parameters are checked by measuring the voltage and current flowing through the object [6]. The voltage from the output of the control unit through a step-up transformer is supplied to the controlled object to which the converter unit is connected. The cable shield is connected via the high voltage potential terminal. After setting the set voltage, the converter unit takes the necessary measurements, processes the received information and transfers it to the control unit (Fig. 7).
Figure 7. Scheme for measuring the insulation parameters ($\tan{\delta}$ and $C$) of the ship cable of KNRE with the Tangens 2000

After measuring the cable hardness, we measured the dielectric loss tangent ($\tan{\delta}$) and capacitance ($C_x$) using the Tangens 2000 instrument. Figures 8 and 9 show the measurement results.

Figure 8. $\tan{\delta}$ value for cable, screen-core measurement mode
The graphs show that at the time point of 156 hours (red line on the graphs), when the insulation toughness value became emergency, the loss tangent value exceeded its initial value. The value of the insulation capacity after a slight decrease in the first 100 hours of testing, by the time 156 hours exceeded the original value and continued to increase.

4. Conclusion
As a result of the tests, it can be established that hardness is the determining parameter for monitoring the condition of the ship cable. Moreover, the rapid diagnostic method [2] has confirmed its effectiveness.

The technique for determining the insulation parameters $\tan\delta$ and $C_x$ can be used both to increase the reliability of the ship cable diagnostics using the hardness control method, as well as an independent control method.

An increase in the values of $\tan\delta$ and $C_x$ indicates a violation of the cable insulation and the need to replace it.

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