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Detection of insulation defects in the wire through measuring changes in its capacitance

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Abstract. The paper describes the technique to detect local wire insulation defects through measuring the wire capacitance. The operating principle of the CAP-10 device is explained. The principal possibility of this device to detect local defects in wire insulation is shown. The experiments showed that the device can be used to detect defects of different types.

1. Introduction

The cable products are widely used in electrical engineering and electronics. The cable product quality determines the quality of electric power and information signal transmission [1]. The considered single-core electric wire is a part of the cable product; therefore, the wire quality affects the finished product quality [1–3]. One of the main normalized values is the wire capacitance per unit length [4, 5]. This parameter is particularly important for a number of cable products such as communication cables, radio-frequency cables and LAN-cables [4].

To calculate the capacitance, the wire is presented as a cylindrical capacitor (Figure 1). The two electrical components of the capacitor are the wire metal core and the wire polymer insulation surface to which the voltage is applied [6].

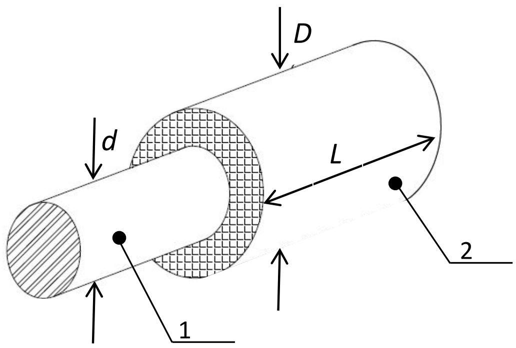

Figure 1. Wire model: core (1); polymer insulation (2).

The capacitance capacitor is calculated using the known equation [7]:

$$C = \frac{2\pi\varepsilon\varepsilon_0 l}{\ln\left(\frac{D}{d}\right)}, \tag{1}$$

where ε is insulating material permittivity; ε_0 is vacuum permittivity; *L* is wire length; *D* is insulation diameter; *d* is core diameter.

The capacitance of the wire depends on its geometric dimensions and insulation electrical properties [5, 8]; therefore, the capacitance change can indicate nominal deviations in geometric or electrical parameters. Consequently, the capacitance change can be the evidence for these deviations [9, 10].

The purpose of the research: to study the capability of the CAP-10 device to detect insulation defects in the wire through measuring the change in its capacitance.

2. Defects of wire insulation

The defects are caused by the breakdown in the technological process of wire manufacturing [11–13]. Therefore, timely detection of wire insulation defects is cost-effective for the cable industry [9, 12, 14]. A defect is product nonconformity to specified requirements [15, 16]. The main types of wire insulation defects are insulation "slicing", cracking, local rupturing, insulation porosity, impurity inclusion, increase or decrease in the outer insulation diameter, etc. [3, 8, 17]. Local defects can cause abrupt changes in geometric dimensions of the wire and electrical properties of the insulation. Consequently, the in-process capacitance changes can be monitored to detect the defects in wire insulation.

3. The operating principle of the CAP-10

CAP-10 can be used to perform in-process testing [18, 19]. It is based on a simple and easy to implement voltmeter-ammeter method. This method implies measurement of the current value to evaluate the wire capacitance value, provided the amplitude and frequency of the applied voltage are known [20, 21].

CAP-10 consists of an electro-capacitive measuring transducer (ECMT), an analogue conversion unit, a digital processing unit and a visualization unit. The physical configuration of CAP-10 is showed in Figure 2 [22].

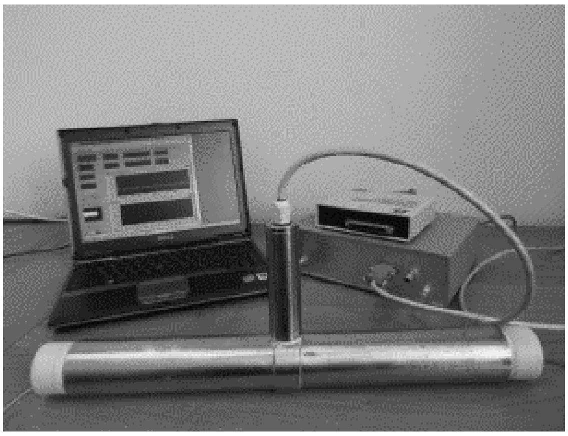

Figure 2. Physical configuration of the CAP-10.

ECMT is a tubular electrode immersed in cooling water of the extrusion line together with the test wire [7, 23]. The ECMT output signal is the current whose amplitude is proportional to the measured

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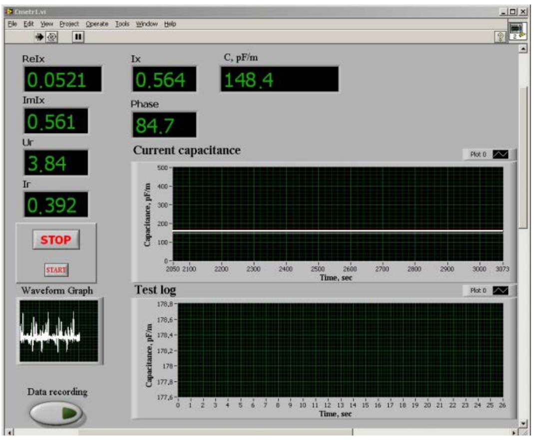
value of the test wire capacitance. The analogue conversion unit generates output signals (Re U и Im U) whose values are proportional to the amplitude values of the current in the measuring electrode. The digital processing unit performs filtering, measured data averaging within 1 second and further digital processing. The visualization unit displays the measurement results in the form convenient for the operator [22].

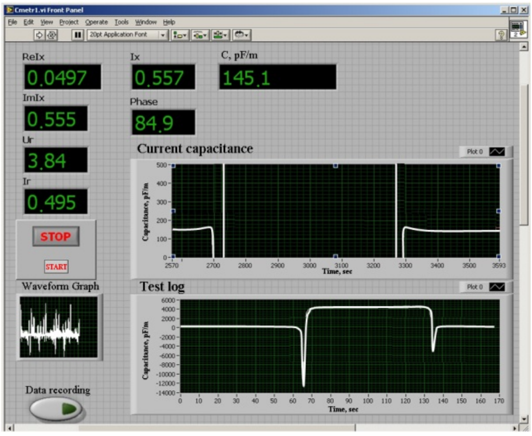
4. Detection of wire local defects using CAP-10

Local defects in wire insulation ("slicing", cracks, rupture, etc) [24] cause abrupt changes in the geometric dimensions and insulation electrical properties [25, 26]. This changes lead to abrupt change in the capacitance value of the test wire [4]. CAP-10 records any slight change in the capacitance (tenths of pF), therefore it can easily detect any abrupt capacitance change.

During manufacturing, the test wire permanently moves inside the ECMT with a known speed [12, 13]. If the wire capacitance is constant, the values recorded by the device remain stable (Figure 3*a*). This indicates that wire insulation is free of defects.



a) Free of defects



b) Defect detected

c) Defect

Figure 3. The front panel of the device CAP-10:
a) Test results for the sample free of defects; *b)* Test results for the sample with detected defect,
c) The sample with defect.

As seen in Figure 3*b*, if the defect (Figure 3*c*) comes into the measuring zone, the wire capacitance abruptly changes. The length of the CAP-10 measuring zone is similar to that of the ECMT measuring electrode (20 cm) [22]. Note that the capacitance change occurs when the defect-containing area is getting in and out of the CAP-10 measuring zone. When the defect-containing area moves through the measuring zone, the capacitance remains constant. When the defect-containing area leaves the measuring zone, the wire capacitance takes its initial value.

Since the test wire permanently moves with a known speed, the defect location can be determined through the time of its detection. The CAP-10 resolution depends on the defect size and the speed of the moving test wire.

The presented capability of CAP-10 extends the scope of its application and provides additional capabilities of spark testing in non-destructive testing in the cable industry [27, 28]. In contrast to spark testing [2, 29], the method employed by the device has an indisputable advantage. Testing can be performed at AC voltage of 3.5 V which is much safer than high voltage used in spark testing [30].

5. Experiment on detection of different types of wire insulation defects

An experiment was performed to test the capability of CAP-10 to detect different types of defects. During the experiment, CAP-10 recorded the capacitance change for different types of wire insulation defects. For this purpose, segments of a single-core electric wire with one brand insulation with a diameter of 1.5 mm were used. The actual capacitance value of the wire segments free of defects was determined in compliance with GOST 27893-88 "Communication Cables. Methods of Tests" [31]. It equals 150 pF/m.

Insulation defects were created artificially on wire segments free of defects. Thus, a set of wire segments with the following types [6, 24, 32] of defects was produced:

- Insulation "slicing" with a length of 1 mm across the total insulation diameter.
- Local insulation rupture with a size of 0.5×0.5 mm.
- A 2.5 mm increased in the outer insulation diameter for the defect with a length of 15 mm.

During the experiment, ECMT with the test wire was immersed in a bath filled with ordinary tap water [33, 34] with a temperature of (22 ± 2)° C. To study the test wire, its movement inside ECMT was simulated at constant speed, and the capacitance value was measured using CAP-10. CAP-10 recorded the capacitance change for different types of defects (Figures 4–6).

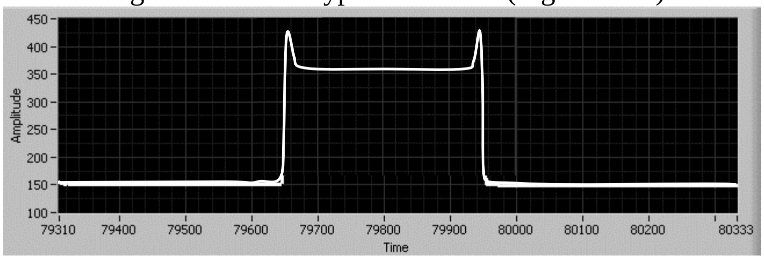


Figure 4. A defect type: insulation "slicing".

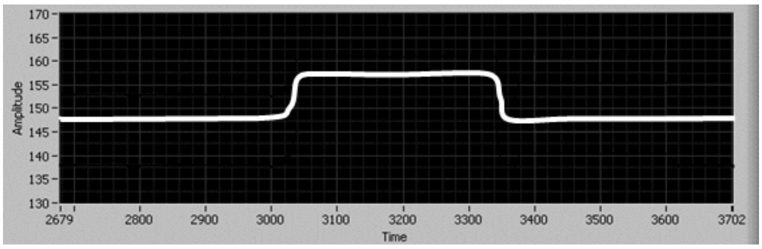


Figure 5. A defect type: local insulation rupture.

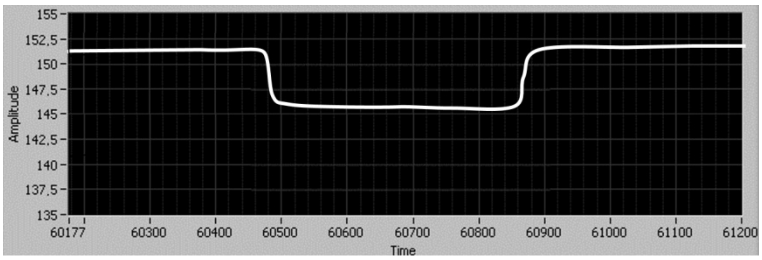


Figure 6. A defect type: increased outer insulation diameter.

The analysis of the results shows that the CAP-10 device identifies different types of wire insulation defects. Further study will aim to determine the CAP-10 sensitivity to geometrical dimensions of the above types of defects.

6. Conclusion

1. The presence of local defects causes abrupt changes in geometric dimensions of the wire and its insulation electrical properties, and consequently, abrupt changes on its capacitance.
2. CAP-10 records any slight capacitance change; therefore it can be used to detect wire insulation defects through measuring capacitance changes.
3. The capability of CAP-10 to detect different types of defects: insulation "slicing", local rupture of insulation, and increased outer insulation diameter is proved experimentally.
4. More research is required to determine the minimum size of defects causing appreciable wire capacitance change (CAP-10 sensitivity).

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