MAGNETIC NONDESTRUCTIVE TESTING AS AN EFFECTIVE INSTRUMENT FOR MONITORING CONDUCTORS AND GROUND WIRES OF OVERHEAD TRANSMISSION LINES

V. Yu. Volokhovskii,[1] A. N. Vorontsov,[2] D. V. Sukhorukov,[3] and A. R. Rudyak[3]

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Magnetic nondestructive testing (NDT) for monitoring the equipment of overhead power lines (OHL) such as conductors, ground wires, and guy wires is discussed. Magnetic NDT allows effective testing of steel ground wires, guy wires, and steel cores of bimetallic conductors. The results of monitoring the conductors and ground wires of 35 – 220-kV OHLs in Rosseti networks are illustrated. The residual load-carrying capacity (strength) of the tested conductors and wires is estimated based on test data. It is concluded that magnetic detectors are effective in testing ground wires, guy wires, and steel cores of bimetallic conductors.

Keywords: overhead transmission line; OHL; monitoring; bimetallic conductor; ground wire; magnetic nondestructive testing; NDT; load-carrying capacity; wire break; residual strength.

The service life of the 35 – 500-kV overhead power lines (OHL) constructed in the USSR in the 1960 – 1970s has already expired. Therefore, tasks accomplishing which extends the life of OHLs have become relevant. One of such tasks is to assess the current condition of OHL equipment. Another task is to justifiably extend the service life of such equipment, maintaining the reliable and trouble-free operation of OHLs. Nondestructive testing (NDT) is one of the effective measures taken by grid companies to reduce the risks of faults and improve the availability for service of OHLs.

The current condition of ground wires, guy wires, and conductors is strongly dependent on the magnitude of loads on them during service. Meteorological factors and mechanical loads affect the distances from the conductors and ground wires to the ground and to crossed objects (buildings and other structures, overhead lines of lower voltage rating, etc.). The degradation of conductors and ground wires is manifested as high residual strains induced by wind and ice loads. Local fatigue strains caused by vibration occur too. Losses of cross-sectional area of ground wires and steel cores of bimetallic conductors (type AS, etc.) occur due to corrosion and/or frictional wear. Moreover, long-term heating by high-load or short-circuit currents leads to a change in the mechanical characteristics and, hence, a reduction in the strength of steel ground wires, bimetallic conductor cores, and their aluminum lays.

With advance in nondestructive testing, grid companies have made an increasing use of ultrasonic testing, heat monitoring, and magnetic flaw detection for the inspection of the OHL equipment. Airborne laser scanning of OHLs allows identifying spans in which the distances from the conductors and ground wires to the ground or crossed objects do not meet the regulatory requirements. The permissible force applied to retighten ground wires/conductors, which is one of the measures to bring unacceptable clearances into conformity with the regulation requirements, is determined by their residual strength. It can be calculated using test data acquired with appropriate instruments (magnetic detectors).

Recently, the nondestructive testing laboratory (NDL) of the INTRON PLUS company have performed, on request of Russian and foreign grid companies, magnetic testing of steel ground wires and cores of bimetallic (steel-bronze and steel-aluminum) conductors of more than 175 OHLs rated at 35 – 500 kV. Special attention was given to special crossings (highways, overhead lines of lower voltage rating, etc.) and water crossings. In some cases, magnetic testing detected flaws such as broken wires and corrosion-induced losses of cross-sectional area of ground wires and steel cores of conductors. The repair and maintenance performed based on the test results made it possible to avoid emergency situations.

In what follows, we will describe the application of the magnetic flux leakage (MFL) method for nondestructive

[1] National Research University “Moscow Power Engineering Institute,” Moscow, Russia; e-mail: volovasilij@yandex.ru
[2] National Research University “Moscow Power Engineering Institute,” Moscow, Russia.
[3] LLC “INTRON PLUS,” Moscow, Russia.

Fig. 1. Visual inspection of conductors of 35-kV OHL using a drone with camera.

testing of steel ground wires and steel cores of conductors (AS type and others, GOST 839–80 E). Examples of test data and calculated values of residual load-carrying capacity (strength) will be given. These data were used to design modification and recovery measures for the inspected OHLs.

MFL Technology and Equipment for Testing Conductors and Ground Wires of OHLs. To monitor the condition of bare conductors (GOST 839–80) and steel ground wires (GOST 3062–80, GOST 3063–80, etc.), the following types of NDT are used: visual inspection (examination) and instrumental methods. Visual inspection of conductors and ground wires, according to the regulation RD 34.20.504–94 [1], is capable of detecting surface defects. Frictional and/or corrosive wear of the inner conductors of ground wires and the steel core of conductors cannot be detected visually. Such defects lead to loss of metallic cross-sectional area of the ground wire or steel core, which is the major characteristic determining their load-carrying capacity.

Recently, operating divisions of grid companies have started using magnetic NDT instruments [2 – 4] to test the condition of steel ground wires, guy wires, and steel cores of conductors (AS, ASK, SB, etc.).

The physics behind MFL (detection of leakage fields occurring near damaged area of a magnetized steel rope) is well known [5 – 7]. The MFL technique with variable or constant magnetic field can be used to detect and analyze defects in cores of bimetallic conductors, steel ground wires, and guy wires. A variable magnetic field is only effective for measuring the loss of metallic cross-sectional area (LMA) of ferromagnetic objects. A constant magnetic field allows detecting both distributed defects (such as LMA of ground wires or steel cores of bimetallic conductors) and local defects (LD) such as broken wires or strands.

Fig. 2. Wheeled system carrying camera along conductors/ground wires.

Irrespective of their design, most modern magnetic flaw detectors have several data channels: channels for detecting distributed faults such as LMA and channel for LDs. Leakage fields are detected with magnetically sensitive Hall-effect sensors and/or inductor coils. When sensors of both types are used simultaneously, the data from them are processed in individual channels and visualized as magnetic leakage chart recordings [8]. To interpret recorded charts, identify defects, determine their parameters, and categorize the condition of the tested object, trained personnel (certified magnetic-NDT experts) should be engaged.

If deenergized, the conductors and ground wires of OHLs can be tested *in situ*. OHLs are disconnected for safe installation/removal of testing equipment (measuring magnetic head (MH) and electronic unit (EU)). Magnetic detectors remain serviceable under both working voltage and induced voltage across conductors and ground wires.

Before magnetic NDT of ground wires and conductors, they should be subjected to visual inspection (examination) to make sure that there are no obstacles to the movement of the MH along them. This can be done with a drone (Fig. 1 [3]) or a wheeled device (Fig. 2 [3]) equipped with first person view (FPV) camera and moving along a conductor or a ground wire.

The installation (Fig. 3) and removal of testing equipment (MH, EU, FPV, and data transmission system) are facilitated with auxiliary equipment (lift, assembly trolley, etc.). To record the magnetic leakage charts of the LMA and LD channels, the MH should be moved (with a synthetic rope attached to it) along the tested segment of a conductor or a ground wire (Fig. 4). If it impossible or difficult to pull the MH in this way (when, for example, testing special crossings, water crossings, etc.), use is made of a remotely controlled, self-propelled, stand-alone device (SD) (Fig. 5).

Many Russian and foreign nondestructive testing laboratories and designated companies use an INTROS magnetic detector (RF pat. No. RU 2204128; US pat. No. 6.492.808), which is a certificated measuring instrument, to test guy wires, ground wires, and cores of bimetallic conductors of

Fig. 3. Installation of magnetic detector on conductor.

Fig. 4. Pulling of a measuring head with a synthetic rope along a conductor.

OHLs. Recently, new NDT instruments, automated magnetic detectors, have become available [9]. In the INTROS-AVTO magnetic detector, the functions of identification of defects, determination of their parameters, and classification of the condition of the tested object are performed automatically, i.e., without human involvement. In this case, an employee of the operating company can use a magnetic detector and its output signals all by himself.

The automated testing of equipment by transferring functions of the detector to an automated NDT instrument is important for improving the availability of OHLs. This allows monitoring the condition of conductors, ground wires, and guys without involvement of magnetic NDT inspectors. Usually, there are no such experts in the staff of companies operating and maintaining OHLs. Also, eliminating the human factor from the interpretation of chart recordings, identifications of defects, and determination of their parameters improves the reliability of test results.

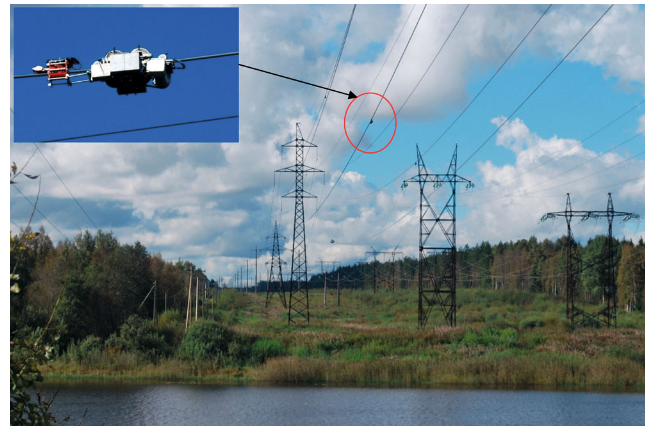

Fig. 5. Self-propelled stand-alone device carrying the measuring head along a conductor.

Assessment of the Condition and Load-Carrying Capacity of Ground Wires and Conductors of OHLs Based on Magnetic NDT Data. The condition of conductors and ground wires determined with magnetic detectors is classified in accordance with corporate regulations. Within an R&D project (contract No. 03-NTTs/07 of July 2, 2007) ordered by the Federal Grid Company of Unified Energy System, the INTRON PLUS company has developed, and the customer approved, a procedure for assessing the condition of composite conductors, ground wires, and guy wires of overhead transmission lines with magnetic nondestructive testing technique. This procedure lists classes of OHL condition and defects of conductors and ropes and provides recommendations on the frequency of magnetic testing. Depending on the class of condition of ground wires and conductors, it is recommended to perform testing as frequently as follows: every six years if the condition is "serviceable" (LMA < 11%) and every three years if the condition is "degraded" (LMA = 11 to 20%). If the condition is classed as "preemergency" (LMA > 20% or the number of wire breaks exceeds the rejection rate), a decision on recovery measures must be made immediately.

The assessment of the load-carrying capacity (strength) of conductors/ground wires is an important component of the testing of their condition. Magnetic testing data alone do not allow determining the degree of reduction in strength. However, the test data (LMA and/or the number of LDs per certain length) can be used as input data to determine the load-carrying capacity of conductors/ground wires using the mechanics of materials and structures and a mechanical model. Such an approach allows determining a number of strength characteristics from which it is possible to draw a justified conclusion on the condition of the tested objects.

Conventional methods for determining the strength of bare conductors of OHLs are well developed [10]. A bimetallic conductor is considered as a set of independent straight steel wires of the core and wires of the lay (aluminum or bronze). The "rod approximation" is used. Such estimates underlie the strength requirements to conductors in [11] and other regulations.

For more accurate strength and stiffness analyses, a ground wire and/or a bimetallic conductor should be considered as a twisted rope, i.e., as a mechanical structure consisting of dissimilar elastic screw elements that jointly deform along the longitudinal axis [12]. The equations of the mechanical state of a rope relate the axial force T and torque M to the generalized tensile strain ε and torsional strain θ:

$$\begin{cases} T = C_{11}\varepsilon + C_{12}\theta; \\ M = C_{12}\varepsilon + C_{22}\theta, \end{cases} \tag{1}$$

where C_{11}, C_{12}, and C_{22} are the effective stiffnesses of a rope as a heterogeneous structure.

The tensile force T induces mainly longitudinal strains in ground wires and conductors. The twisting (detwisting) effect can as a rule be neglected. This is why the dominating quantity in (1) is the longitudinal stiffness C_{11} depending on the stiffness and geometry of wires:

$$C_{11} = \sum_{j=1}^{J} m_j EA_j \cos^3 \alpha_j. \tag{2}$$

where the summation is over layers of wires ($j = 1, ..., J$); m_j is the number of wires in the jth layer; E_{Aj} and α_j are the cross-sectional stiffness and the angle of twist of wires about the rope axis in the jth layer.

During long-term operation, the structural components of bimetallic conductors (wires of the lay and core) gradually undergo irreversible deformations. To allow for this effect, expression (2) for C_{11} should be represented in the form

$$C_{11} = \sum_{j} m_j \frac{EA_j}{1 + EZ_j(\tau)} \cos^3 a_j,$$

where $Z_j(\tau)$ are empirical functions of time τ (creep functions), which are different for steel and aluminum/bronze wires [14].

The strain ε of the rope (the core of a conductor or a ground wire) is determined for given tension T and transforms into tensile, $\varepsilon^{(j)}$, bending, $b^{(j)}$, and torsional, $t^{(j)}$, strains of wires of the jth layer in screw coordinates:

$$\varepsilon^{(j)} = \varepsilon \cos^2\alpha_j; \; b^{(j)} = -\varepsilon \frac{\sin^2 \alpha_j \cos^2 \alpha_j}{r_j};$$

$$t^{(j)} = -\varepsilon \frac{\sin^3 \alpha_j \cos \alpha_j}{r_j}, \tag{3}$$

where r_j is the radius of twist of the jth layer. The normal, σ, and tangential, τ, stresses are determined from Eq. (3). An appropriate failure criterion is used to reduce the compound stress state at a critical point of the most loaded wire to an equivalent linear stress state. For example, $\sigma_{eq} = \sqrt{\sigma^2 + 4\tau^2}$.

From an engineering standpoint, the degradation associated with loss of the load-carrying capacity of a conductor/ground wire can naturally be interpreted as a reduction in the residual strength because of the accumulation of defects compared with the initial (faultless) state. The residual strength can be used to assess the condition of a conductor/ground wire. When the residual strength tends to the limit, it is necessary to take the appropriate measures to ensure the trouble-free operation of the OHL.

The strength of a ground wire is calculated in several steps. First, the test data (interpreted chart recordings from the LMA and LD channels of the magnetic detector) are used to draw "defect charts," i.e., parameters and location of distributed and local defects. "Defect charts" are included in the input data for RopeStrength software (state registration certificate No. 2009615284 of September 24, 2009). Strength analysis is performed for three cases: a ground wire with no defects, a ground wire with detected LMA, and a ground wire with LD (wire breaks). In each case, the longitudinal strain of the ground wire as a whole is calculated from Eqs. (1), and the tensile, bending, and torsional strains in the wires and the associated stresses are determined by formulas (3). Finally, the maximum equivalent stresses in the most stressed wire are determined using the appropriate failure criterion, and the residual strength is calculated:

$$n = \frac{\sigma_b}{\max \sigma_{eq}}. \tag{4}$$

where σ_b is the ultimate tensile strength of the wires. The relative losses of strength RLMA and RLD associated with LMA and LD are defined as

$$R_{LMA} = 1 - \frac{n_{LMA}}{n_0}; \; R_{LD} = 1 - \frac{n_{LD}}{n_0}, \tag{5}$$

where n_{LMA} and n_{LD} are the residual strength coefficients for a rope with defects; n_0 is the residual strength coefficient of an as-delivered rope (theoretically, free of defects). The parameters R_{LMA} and R_{LD} are determined independently, according to the cumulative damage hypothesis in structural mechanics. The resultant loss of cross-sectional strength R is determined as the superposition

$$R = R_{LMA} + R_{LD}. \tag{6}$$

The residual strength coefficient of the conductor and/or ground wire is expressed as

$$n = n_0(1 - \max R), \tag{7}$$

where max R is the maximum loss of strength. The residual strength coefficient n must be greater than the minimum per-

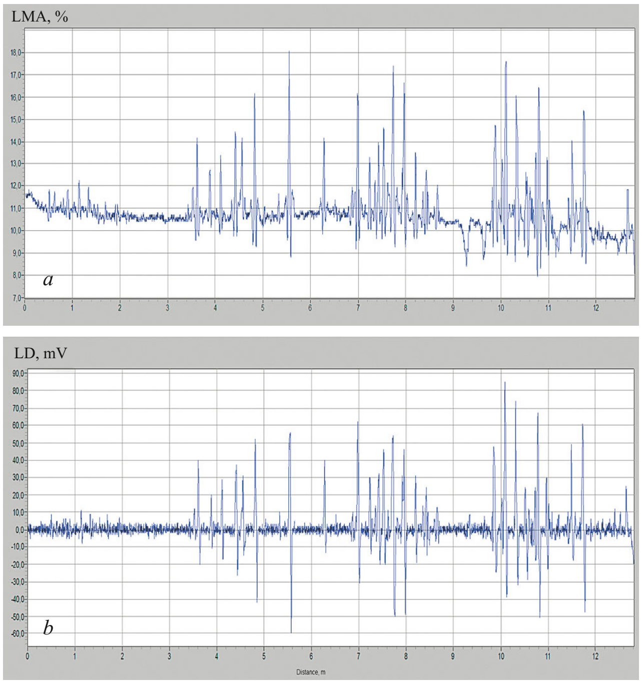

Fig. 6. Chart recordings from LMA (*a*) and LD (*b*) channels for the core of BS 185/43 steel-bronze conductor.

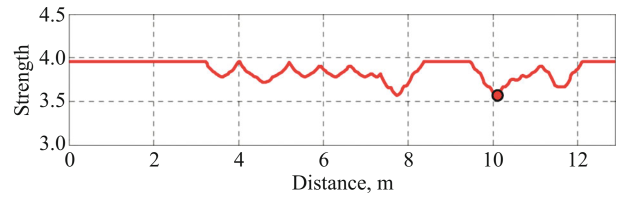

Fig. 7. Distribution of strength along BS 185/43 conductor segment.

missible value n_*, i.e., $n \geq n_*$, throughout the entire service life. Otherwise, the conductor or ground wire with cumulative damage should be replaced.

The strength analysis of AS-type conductors was performed in the same way as for ground wires, assessing the stress state by methods adopted for compound structures. The current values of n or R are proposed to use to assess the condition a conductor/ground wire with defects.

As an example (as in [3]), we will discuss the calculation of the residual strength of the BS 185/43 steel-bronze conductor segment of the 35 kV Ladozhskaya-3 OHL crossing the Neva River. Figure 6 shows the chart recordings from the LMA and LD channels of INTROS (MG 20–40) magnetic detector used to test the core of a wire of length $l = 13$ m. The chart recordings are processed (interpreted) using Wintros software (state registration certificate No. 2005611017 of April 27, 2009).

Figure 6*a* indicates that the maximum loss of cross-sectional area in this segment is 18%, while Fig. 6*b* suggests that there is a wire break. A criterion that the steel core of a bimetallic (steel-bronze BS 185/43) conductor is broken is the shape of the signal (in mV) from the LD channel and its amplitude's exceeding the noise level and the threshold corresponding to a break of one wire.

Figure 7 illustrates the calculated distribution of n along the tested conductor segment.

To calculate this coefficient, the rated conductor tension T was assumed to be equal to 30 kN. The red full circle at $l^* = 10.1$ m corresponds to the minimum value $n = 3.57$. This minimum can be considered an actual residual strength coefficient n for the tested segment. The dips in the curve correspond to LDs (wire breaks) of the steel core. The mechanical model of a defective conductor used in [12, 15] accounts for the capability of broken wires to take up tension with distance from the break due to friction. The decrease in the residual strength compared with its initial value ($n_0 = 4.23$) is due to the distributed loss of cross-sectional area because of corrosion and frictional wear of core wires.

The above assessments are in agreement with [11] where the strength requirements are formulated in terms of allowable stresses: the stresses in a conductor must not exceed allowable values that depend on the type and grade of conductor and the characteristic operating conditions. For example, for AS-type conductors and average annual temperature, it is assumed that $[\sigma] = 0.3\sigma_b$. In structural mechanics, this relation has the form $[\sigma] = \sigma_b/[n]$, where $[n]$ is the rated residual strength coefficient. The allowable tension of a new conductor is selected so that $n_0 \geq [n] = 3.3$.

There are some problems and features encountered in calculating the residual strength of conductors and ground wires with detected defects. The change in the strength of structural materials during long-term operation should be taken into account. Unfortunately, there are very few reliable and ordered data on the long-term strength of bimetallic conductors (AS type, etc.). That such studies are important and expedient is beyond question.

As calculations show, the loss of strength of bimetallic conductors is less than the LMA of the core because some of the load is taken up by the wires of the lay. Unlike the rod approximation [10], the twisted-rope model [12] used to design conductors or ground wires accounts for the nonuniform stress distribution over the cross-section caused by the tension, bending, and torsion of the wires. This model predicts higher loss of strength than the rod approximation does based on the ultimate loads. The percentage loss of strength of ground wires is higher than the LMA for the same reason. The more complex the structure of the core, the more the difference between the residual strengths of new conductors and conductors with defects.

Results of Magnetic Testing of Conductors and Ground Wires of Rosseti OHLs. Next, we will use the tests of conductors and ground wires carried out by the Lenénergo company (branch of the Rosseti company) as an example to illustrate the efficiency of magnetic detectors in inspections of OHLs operated for a long time (35 – 40 years and longer).

Lenénergo mainly tested water crossings (the rivers of Neva, Volkhov, Vuoksa, etc.) of 35 – 110-kV OHLs. The crossings tested are listed in Table 1.

The phase conductors were tested in 27 spans of 26 OHLs rated at 35 – 110 kV, and ground wires were tested in 15 spans. In some cases, significant defects of ground wires and conductor cores were detected. For example, the condition of conductors and ground wires in eight of the ten water crossings tested by the Gatchina Electrical Networks branch of Lenénergo was classed as serviceable. Their service life was extended for six years. It was recommended to perform the next testing in 2019. The condition of the conductors and ground wires of the Kolpino-4 OHL (in the span between towers 8 and 9) and the conductors of the Chudovo-2 OHL (in the span between towers 44 and 45) was classed degraded. The test data for these OHLs are summarized in Table 2.

The service life of the AS-150/24 conductors and ST 50 ground wires of the Kolpino-4 OHL and the AS-150/19 conductors of the Chudovo-2 OHL was extended for three years.

The inspection of the Severnaya-10 OHL crossing of the Vuoksa River detected no breaks of the ground wire (ST 50), but detected considerable corrosive wear. The maximum loss of cross-sectional area of the ground wire was 14.6%, and the relative loss of load-carrying capacity $R = 15.33\%$. The condition of the ground wire was classed as degraded, yet it was recognized suitable for further service. The phase conductors (AS-120/19) of this OHL did not have broken wires in the core, but displayed considerable corrosive wear. The maximum LMA = 12.8% (at 36.2 m), and the relative loss of strength $R = 6.41\%$. The condition of the conductors was classed as degraded, but they were recognized suitable for further service. It was recommended to inspect the conductors and ground wires of this crossing next time in three years.

The testing of the conductors of the Ladozhskaya-3 and -4 35 kV OHLs crossing of the Neva River revealed more problems. The conductors in the span between towers 42 and 43 are of BS-185 type (steel-bronze; conductor diameter 19.6 mm; steel core diameter 8.4 mm). At the time of testing, these conductors had been in service for more than 45 years.

TABLE 1. Tested Water Crossings in Lenénergo Branches

OHL	Water body crossed	OHL voltage, kV	Tested object (span, test sample)
Gatchina Electric Networks			
Baltiiskaya-1	Izhora River	110	11 – 12
Prometei-2	Izhora River	110	110 – 111
Kolpino-4	Izhora River	110	8 – 9
Batovskaya-1	Oredezh River	35	4 – 5
Batovskaya-2	Oredezh River	35	4 – 5
Andrianovskaya	Tosna River	35	87 – 88
Lyuban’-2	Tigoda River	35	49 – 50
Trubnikovskaya-1	Tigoda River	35	10 – 11
Trubnikovskaya-2	Tigoda River	35	97 – 98
Chudovo-2	Tosna River	110	44 – 45
Vyborg Electric Networks			
Gromovskaya-3	Vuoksa River	110	Test sample of conductor
Gromovskaya-5	Vuoksa River	110	Test sample of conductor
Vuoksa-3	Vuoksa River	110	1 – 2
Severnaya-10	Vuoksa River	110	Twr. 32, HPP-10
Kuznechnaya-1	Lake	110	66 – 67
Kuznechnaya-2	Lake	110	66 – 67
BL “Vyborg–1”	Saimaa Canal	110	Test sample of conductor
BL “Vyborg–2”	Saimaa Canal	110	23 – 24
Sapernaya-3	Vuoksa River	35	112 – 113
St. Petersburg High-Voltage Electric Networks			
Ladozhskaya-3	Neva River	35	42 – 43
Ladozhskaya-4	Neva River	35	42 – 43
Tikhvin Electric Networks			
Kirishi-1	Volkhov River	110	13 – 14
Kirishi-2	Volkhov River	110	13 – 14
Kirishi-4	Volkhov River	110	14 – 15
Kirishi-4	Volkhov River	110	86 – 87
Novaya Ladoga Electric Networks			
Volkhov-5	Syas’ River	110	19 – 20
L-47	Oyat’ River	35	28 – 29

Fig. 8. Crossing of the Ob' River by 110 kV Kudelinskaya – Shubinskaya and Roslyakovskaya – Priobskaya – Shubinskaya OHLs.

The magnetic testing detected a considerable corrosion-induced LMA of the cores and many wire breaks in the cores. The test data for the conductors between towers 42 and 43 and the calculated values of the relative loss of strength are given in Table 3.

The condition of the conductors of the Ladozhskaya-3 and -4 OHLs crossing the Neva River was classed as pre-emergency. Based on the test data, the Lenénergo line service decided to replace the old BS-185 steel-bronze conductors with modern bare conductors.

One of the latest inspections performed by the NITRON PLUS nondestructive testing laboratory involved MFL testing of Tyumen'énergo 110 kV OHLs. The Kudelinskaya – Shubinskaya and Roslyakovskaya – Priobskaya – Shubinskaya crossings of the Ob River (Fig. 8) were tested in April, 2019.

TABLE 2. Results of Testing Conductors/Ground Wires of Kolpino-4 and Chudovo-2 OHLs

OHL	Span	Object (conductor/ ground wire)	Type of conductor/ground wire	Detected defects, their parameters	Condition of conductor/ ground wire
Kolpino-4	8 – 9	Lower conductor	AS-150/24	No core wire breaks detected. LMA = 9.5% (at 131.2 m)	Serviceable
		Middle conductor	AS-150/24	No core wire breaks detected. LMA = 8.1% (at 2.1 m)	Serviceable
		Upper conductor	AS-150/24	No core wire breaks detected. LMA = 11.1% (at 187.2 m)	Degraded
	8 – 9	Ground wire	ST-50	Two broken ground wires at 139.2 m. LMA = 14.3% (at 139.2 m)	Degraded
Chudovo-2	44 – 45	Upper conductor	AS-150/19	No core wire breaks detected. LMA = 10.8% (at 66.4 m)	Serviceable
		Middle conductor	AS-150/19	No core wire breaks detected. LMA = 12.0% (at 65.5 m)	Degraded
		Lower conductor	AS-150/19	No core wire breaks detected. LMA = 15.1% (at 88.9 m)	Degraded

TABLE 3. Results of Calculating Relative Loss of Strength of Tested Conductors of Ladozhskaya-3 and -4 35 kV OHL

OHL	Tested object (phase conductor)	Maximum LMA of conductor core, %	Relative loss of strength of conductor, %
Ladozhskaya-3 35 kV OHL	Lower	19.7	17.6
	Middle	18.1	16.1
	Upper	20.3	21.2
Ladozhskaya-4 35 kV OHL	Lower	28.4	24.4
	Middle	35.9	27.5
	Upper	36.3	27.7

Both lines were commissioned in 2002. In these special crossing spans, AZhS500/336 type conductors are used. The testing revealed that after long-term service (more than 16 years), the condition of the conductors in both crossings is still serviceable. There were no wire breaks detected. The maximum LMAs of the conductor cores are within 1.8 – 2.1%.

Figure 9 shows, as an example, the LMA and LD chart recordings for the lower phase conductor of the Kudelinskaya – Shubinskaya 110 kV crossing (span between towers 46 and 45) of the Ob' River.

The length of the tested segment $l = 415.7$ m. The maximum LMA of the core was 2.0% at $l = 226.5$ m (the origin 0 m is behind the vibration damper near tower 46).

The next magnetic testing of the these crossings is recommended to perform in six years.

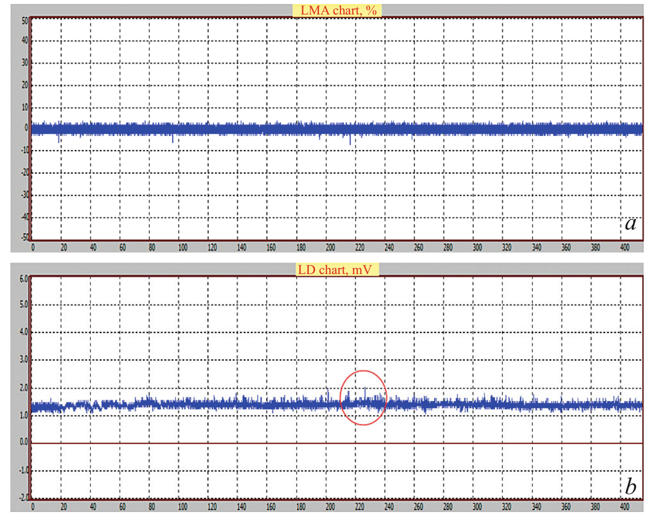

Fig. 9. LMA (*a*) and LD (*b*) chart recordings for the core of the lower conductor of the Kudelinskaya – Shubinskaya 110 kV OHL crossing (the span between towers 46 and 45) of the Ob' River.

CONCLUSIONS

1. Magnetic flaw detection is an effective method for nondestructive testing of the OHL equipment such as bimetallic (AS type, etc.) bare conductors, steel ground wires, and guy wires. This method has been more and more widely used by the Rosseti branches in inspecting 35 – 110 kV OHLs to assess the condition of their equipment.

2. In some cases, magnetic testing indicated degraded or preemergency condition of conductors/ground wires and, in other cases, allowed extending their trouble-free service life to avoid costly repair or replacement of equipment.

3. The residual strength of a conductor/ground wire calculated based on the magnetic test data can be used as an additional argument for the operational personnel to make appropriate decisions. Periodic magnetic inspection allows assessing the rate of aging of conductors and ground wires and developing a method for quantitative assessment of their remaining service life.

4. The use of magnetic flaw detection to test the condition of OHL equipment (bimetallic conductors, steel ground wires, and guy wires) should be included in regulations on maintenance and testing of OHLs.

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