Journal of Power Technologies 100 (2) (2020) 138–143

Verification of the magnetic method in testing of the modified composite core of overhead conductors

Mariusz Szot *, Piotr Szade †

Abstract

ACCC/TW conductors deliver excellent electricity transmission results, boosting overall power system efficiency and capacity. Detracting from their many advantages is the propensity of their composite cores to suffer cracking under excessive bending. This article presents a concept for modifying construction and a testing method to determine the technical state of the conductor core after installation in its place of operation. The technique uses an existing method for magnetic testing of steel cables. Tests were conducted on a series of conductor models with cores containing epoxy resin with an addition of a ferromagnetic FeSi 15 powder. The measurements showed the tests were able to detect small crosswise gaps and cracking simulated in the core. The accuracy of the method is determined by the concentration of a magnetic component in the core.

Keywords: composite core conductor, magnetic testing, power transmission

1 Introduction

Modern power transmission technologies minimize losses and increase effectiveness of the power grid. Innovative types of electrical conductors, based on new construction and material solutions, are an important aspect of developments in this field. Nevertheless, slow progress is being made in terms of checking the technical condition and safety of power lines immediately prior to starting full operational use. The following work presents an experimental method of checking the state of composite cores of ACCC/TW conductors using existing and widely used methods of magnetic testing of steel wire ropes.

ACCC/TW (aluminum composite core conductor/trapezoidal wire) electric conductors (Fig. 1) are a modern solution in the field of electric energy transmission, developed to improve key properties of transmission lines. The design utilizes a composite core, composed of glass and carbon reinforcing fibers in an epoxy resin matrix, manufactured using methods of pultrusion. This method delivers higher tensile strength and much lower density than the steel cores that are widely used in conventional ACSR (aluminum conductor steel reinforced) conductors. Trapezoidal, annealed, 99.7 % pure aluminum wires are also used, which results in a bigger share of aluminum in the overall cross-section of the conductor and a higher maximum work temperature of up to 250 C [1]. Along with the low coefficient of linear expansion, those properties qualify this design for the HTLS group of conductors (high temperature – low sag) [2].

Figure 1: Sample of an ACCC/TW conductor

The structure of the ACCC conductor determines a number of its advantages: low weight, low sag and low electrical resistance. Consequently, power lines based on this solution feature greater capacity, lower transfer losses and safety of work during an overload. Those features are especially significant when meeting national obligations in terms of energy efficiency and limiting CO2 emissions. Their main disadvantage is price (3 times higher than its ACSR equivalent), but in light of the possibility of achieving quick and easy power line modernization it is often an economically justified investment. Unsurprisingly, as of 2016 around 33 000 km of ACCC type conductors were installed worldwide [2]; [3].

Nevertheless, the technology has a limiting factor, which is the higher allowed bend radius than its ACSR counterparts [4]. Tests and simulations show that subjecting ACCC conductors to excessive bending may

*Central Mining Institute Plac Gwarków 1, 40-166 Katowice, Poland, e-mail
†Central Mining Institute Plac Gwarków 1, 40-166 Katowice, Poland, e-mail

cause damage to their structure, resulting in cracking of the epoxy matrix, kinked carbon fibres and delamination at the glass/carbon interface [4]; [5]; [6]. Examples of damage analyzed by Burks are presented in Fig. 2.

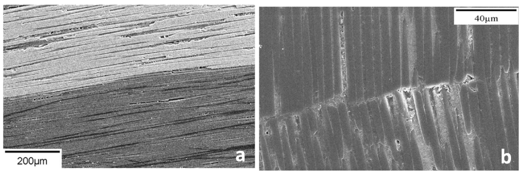

Figure 2: SEM imaging of damage to the composite core subjected to bending

In that research it was found that the bend radius causing significant damage to the core, manifested externally as a series of acoustic emissions, is around 280 mm, and a critical bend radius, resulting in breaking of the reinforcing fibres and breaking of the core – around 233 mm. In the case of four point bending, equivalent to 80 % and 90 % of the core's flexure strength (respectively 292 mm and 259 mm bend radius), it results in damage to the matrix in the form of micro cracking. Such bending can occur as a result of errors in the conductor installation process or usage of inappropriate equipment. As established by Burks, damage to the matrix of the tested cores has no direct influence on their tensile strength, although discontinuities can have a major impact on performance of the conductor during use and on its mechanical and fatigue characteristics [6].

The magnetic rope testing method (MRT) is based on the phenomenon of dissipation of the magnetic field in areas of damage in a steel cable, previously magnetized in a constant magnetic field, registered by inductive or hallotronic sensors. The measurement is conducted using dedicated testing heads and registered on tape charts, or digitally by a defectograph. This technique has been used since the 1940s to check the technical condition of steel wire ropes in lifts, cableways, drilling equipment among others. It enables safety officials to pinpoint places of wire breakage, attrition, corrosive damage and make quantitive calculations of loss of a cross section of cable [7]. An MRT head along with a defectograph is shown in Fig. 3.

A typical MRT head consists of strong permanent magnets, an inner inductive sensor (to detect material loss), an outer inductive sensor (to estimate its depth), a hallotronic sensor (simplifying detection of losses with elongated characteristics) and also a gauge of cable movement relative to the testing head [8]. An example of an MRT measurement graph is shown in Fig. 4.

Figure 3: MRT testing head with a defectograph

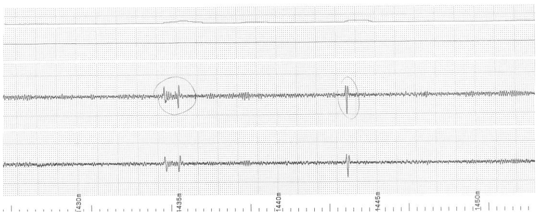

Figure 4: Example of a MRT chart

The purpose of this work was to verify the testing potential of a new method of controlling the continuity of composite cores of electric conductors. The method consists of:

- Adding a ferromagnetic agent to the composition of the core in the form of a FeSi powder with granulation of 0.063 mm or similar, by introducing it into epoxy resin constituting all or part of the matrix of the composite,
- Applying or adapting existing methods of magnetic rope testing (MRT) to detect damage and discontinuities in the structure of the core.

For this goal a series of models of a core were made, containing epoxy resin with an addition of FeSi powder, and a series of MRT measurements were performed, with models as a substitute for cores of ACSR conductor sections.

To assess the accuracy of the method, various amounts of ferromagnetic powder were used in preparation of the models.

2 Methodology

To model composite cores containing ferromagnetic particles, 4 test samples (Fig. 5) were made in the form of PVC tubes with inner diameter of 5 mm filled with a mix of Epidian 5 epoxy resin, Z1 hardener and

Table 1: FeSi content of test resin mixes

Sample No.	FeSi Content g	FeSi Content cm^3
1	250	35.7
2	200	28.6
3	150	21.4
4	100	14.3

Table 2: FeSi content in 1 m of tested cores

Sample No.	FeSi Content / m g	FeSi Content / m cm^3
1	48.7	7.0
2	42.0	6.0
3	34.1	4.9
4	24.8	3.5

various amounts of MFeSi 15 powder with particle size of up to 0.063 mm. Nominal specific density of the powder was 7.0 g/cm^3 and this value was used in calculations.

Figure 5: Model of the composite core containing FeSi powder

In each mix, 60 cm^3 (70.8 g) of Epidian 5 resin with 5 cm^3 of Z1 hardener was used. FeSi additions for each of the samples are listed in Table 1. To achieve the degree of elasticity of the models to allow for bending during handling and testing, lower amounts of Z1 hardener were used than recommended by the producer.

Based on the ratio of components of the mixes, the contents of the FeSi powder per one meter of each core were calculated (Table 2).

The mixes were introduced into the PVC tubes gravitationally or by using slight pressure and then left to harden. In this way 120 cm long samples were acquired. The longitude of core models that could be acquired was limited by the viscosity of the mix, especially with higher contents of FeSi powder. Cores were then cut in half. A piece of empty PVC tube was used to make spacers 1 mm, 3 mm and 5 mm in width, to substitute for damage or discontinuities of the core. The role of the aluminum part of the conductor was fulfilled by layers of round aluminum wires, acquired by removing a steel core from 4 lengths of 236-AL1/40-ST1A conductor with a nominal diameter of 21.7 mm. During the tests, the core models, separated in the middle by a spacer, were introduced into empty spaces left by the steel cores. The prepared conductor models (Fig. 6) were subjected to MRT tests for every variant of FeSi content and width of spacer.

Figure 6: Model of the conductor with a composite core enriched with FeSi

The testing system (Fig. 7) consisted of a GP-3ARH MRT testing head (Fig. 7a) equipped with a set of permanent magnets (Fig. 7b) and an inductive sensor (Fig. 7c). Tests were performed by passing 4 models of electric conductor (Fig. 7d) through the testing head multiple times using a reciprocating motion with a speed of approximately 1 m/s, during which a core containing FeSi powder (Fig. 7e) was magnetized, and a spacer (Fig. 7f) caused a dissipation of the magnetic field proportional to the width of the defect.

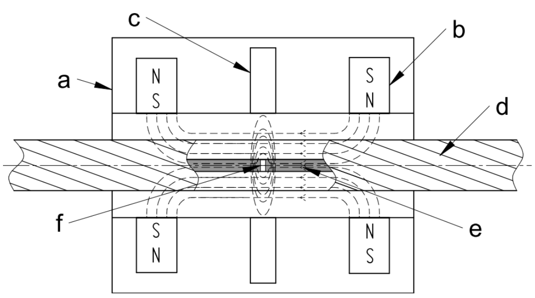

Figure 7: Schematic diagram of the testing head during measurement

The signal generated by the testing head was registered digitally using a MD121 defectograph with measurement sensitivity set to 1 mV/div and sampling resolution of 5000 samples/s. The software provided with the device (Fig. 8) was used to browse, view and analyze the data gathered, detecting peaks of the signal caused by the gap inserted into the cores.

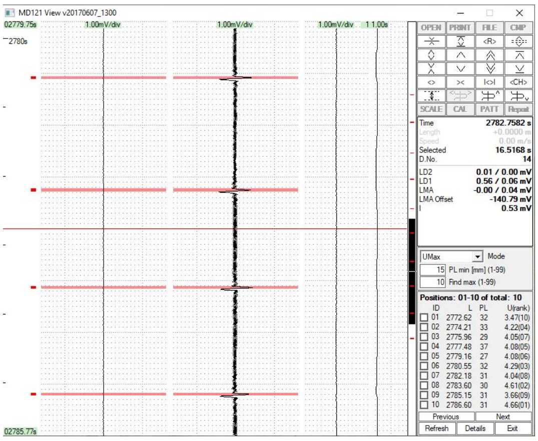

Figure 8: MD121 View software interface

The cores of the tested models were assembled from two identical parts, composed of an epoxy resin with various amounts of Fe Si 15 powder added, separated by spacers of 1 mm, 3 mm or 5 mm. Additional measurements of conductors with a cut core with no spacer (0 mm) were also performed. Due to the dependence of the signal strength on the speed of movement of the conductor relative to the inductive sensor and the non-availability of any speed compensation function owing to the dimensions of the samples, the test results should be primarily considered in a qualitative manner.

3 Results

Values of highest signal peaks Umax recorded during testing, sorted by ferromagnetic powder content, are presented in Table 3.

Table 3: Results of testing of the conductor models using the MRT method

Sample No.	FeSi Content	Signal peak Umax, mV			
		Width of spacer, mm			
	g/m	0	1	3	5
1	48.7	1.71	4.13	7.58	12.92
2	42.0	1.15	3.06	5.36	7.77
3	34.1	0.64	1.46	3.85	6.08
4	24.8	0.50	1.08	1.60	2.27

As the primary function of the proposed method is detecting discontinuities and damage to the composite core of the conductor, it would be mostly based on the analysis of charts generated by the defectograph (Fig. 9).

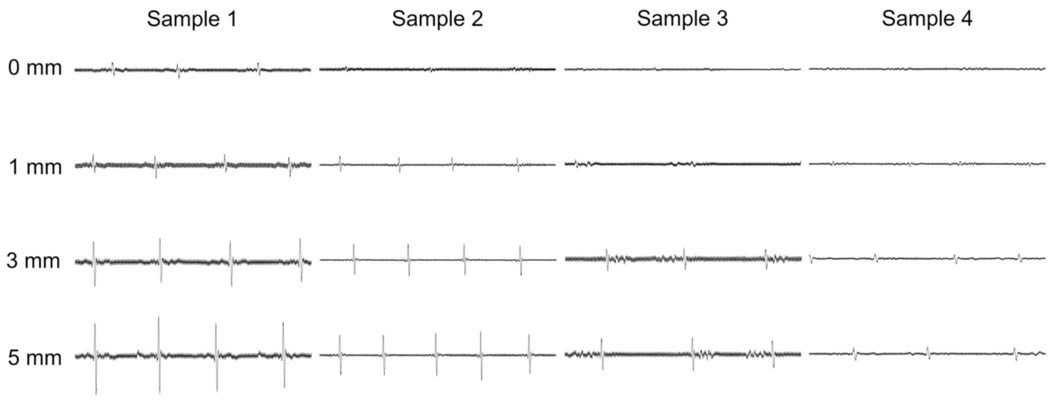

Figure 9: Fragments of charts registered during testing of samples

4 Result analysis

MRT methods were used to test electric conductor models . Due to model geometry, the test results can be used to estimate the accuracy of the proposed method in detecting discontinuities and damage perpendicular to the axis of the conductor.

Sample 1, characterized by the highest content of FeSi powder (48.7 grams per meter of conductor), exhibited an easily distinguishable signal peak for all of the applied spacers. It also detected a crack in the core of the conductor, which indicates the method's potential to indicate early fractures occurring during installation.

The slightly lower ferromagnetic content of 42.0 g/m in sample 2 caused the signal generated by the cut in the conductor to be practically lost in the signal noise of the measurement. Nevertheless, gaps of 1 mm and wider were easily detectable during MRT measurement.

Further decrease of FeSi powder content in the model negatively impacted accuracy and detecting the presence of the 1 mm spacer in the sample 3 proved inconclusive with the test parameters that were applied.

Sample 4, containing the lowest amounts of ferromagnetic additive of just 24.8 g/m, detected 3 mm and 5 mm gaps in the core of the conductor, which still guarantees detection of a critical failure of the core.

Part of the background noise in the signals visible on the measurement charts is caused by air bubbles contained in the resin mix, which are the result of method of production of the models. It is safe to assume that this problem would not occur during continuous manufacture of conductor cores, and their greater homogeneity would in turn result in this testing method enjoying greater accuracy.

The tests demonstrated a relationship between the width of the gap in the core, FeSi content in its epoxy matrix and the strength of the signal registered by the defectograph at the place of the simulated core damage (Fig. 10).

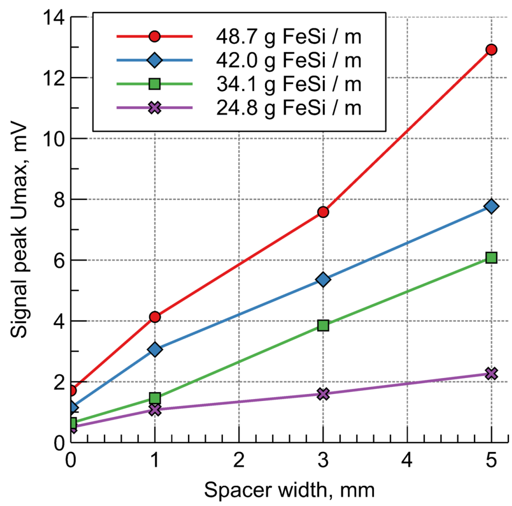

Figure 10: Dependence of damage detection signal on gap width and FeSi content

Greater contents of ferromagnetic powder enhance the sensitivity and accuracy of the analyzed method for verifying the continuity of the core, simultaneously causing the overall weight of the conductor to increase. The test results open up the possibility of using existing MRT methods to verify the continuity of composite cores of electric conductors after enriching them with functional ferromagnetic particles. Further research is needed to evaluate the full potential of this method, considering the core damage of axial character, fully sized samples and fully functional prototypes of conductors.

5 Summary

The ACCC/TW type conductors exhibit many advantages and their range of application is set to increase. Adding functional, magnetic elements to their construction would make it possible to use existing methods of magnetic wire rope testing to ascertain the technical state of their cores before and after installation in the place of operation. The sensitivity of detecting damage and discontinuities of the core is dependent on the content of ferromagnetic elements and the manner in which the measurements are conducted.

This work was funded by The Ministry of Science and Higher Education in Poland under grant No. 10100317-181.

Conflict of interest: The authors declare that they have conflict of interest.

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