Hungarian Materials and Chemical Sciences and Engineering, Volume 47, No. 1 (2023), pp. 63–71.
http://doi.org/10.32974/mse.2022.006

THE EFFECT OF SURFACE TREATMENT ON THE AUDIBLE NOISE OF A HIGH VOLTAGE CONDUCTOR

MÁTÉ SEPSI[1] – ANAS JAWABREH[2] – GYÖRGY NEMCSIK[3] –
PÉTER BARKÓCZY[4]

Abstract: The conductors of high-voltage electrical transmission networks emit strong noise in wet weather. It is caused by the formation of corona radiation on their surface. The high electrical field gradient at the surface deforms the water droplets formed on the conductors' and the droplets amplify the corona radiation. The corona radiation not only indicates noise, but it is a loss too. The reduction of the corona radiation also reduces the loss of the transmission. Reducing the intensity of corona radiation can be achieved by improving the wettability of the surface to hinder the formation of large droplets. One way to do this is to blast the surface. However, in addition to the study of wettability, an important question is how the conductor behaves during operation. It is possible to examine in laboratory conditions with the application of high voltage and artificial rainfall. The experience gained from this type of experiment is presented in the article.

Keywords: Surface treatment, High voltage, Conductor, Corona radiation, Noise level

INTRODUCTION

A classic field of application of aluminum alloys is the electrical industry [1], especially high-voltage power conductors [2], in addition to the wide range of applications of aluminum alloys [3, 4]. Also in power lines, several types of aluminum alloys and composites are used in various constructions. The performance of core alloys and composites is continuously tested for each application [5, 6], and the development of new materials is also continuous [7, 8]. New materials and solutions are slowly being transferred to power line production and application. This is due to the conductors' long service life and the electricity supply security issues [9].

The requirements of aluminum wire materials for power lines are low electrical resistance and high tensile strength [10]. The individual conductor constructions give intervals for these values, in which the material of the reinforcing or supporting wire or strand plays a major role. Classically, we are talking about a strand consisting of hard-drawn high-carbon steel wires. In the new developments, composite with a carbon fiber reinforced polymer matrix or

---

[1] Institute of Physical Metallurgy, Metal Forming and Nanotechnology, University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
anasjawabreh0012@gmail.com

[2] Institute of Physical Metallurgy, Metal Forming and Nanotechnology, University of Miskolc
H-3515 Miskolc-Egyetemváros, Hungary
femsepsi@uni-miskolc.hu

[3] FUX Co., Miskolc
H-3527 Miskolc, Besenyői str. 8, Hungary
fembarki@uni-miskolc.hu

[4] Institute of Physical Metallurgy, Metal Forming and Nanotechnology, University of Miskolc, FUX Co. Miskolc
H-3515 Miskolc-Egyetemváros, H-3527 Miskolc, Besenyői str. 8, Hungary
fembarki@uni-miskolc.hu, peter.barkoczy@fux.hu

a ceramic-reinforced aluminum matrix composite are applied [11]. Studying the material, phase transformations, and performance of reinforcing and supporting strands and wires are also important issues [12, 13]. Composite durable wires have brought significant development in this area [14]. So current developments are turning to aluminum wires.

An important issue during application is the behavior of the surface of the wires. In particular, the electrical field gradient formed on the surface and the resulting corona radiation caused is one of the main issues during operation [15]. In this case, both the loss due to corona radiation and the noise effect caused by partial discharges [16]. Both problems are related to the wettability of the surface of aluminum wires [17], thus, it is necessary to test the wettability of the water.

The surface of the cold-drawn aluminum wires is hydrophobic after the wire drawing operation, which must be turned into hydrophilic [18]. There are several possible solutions to this [19, 20]. There is considerable potential in the special properties of thin layers [21] or in the formation of an oxide layer developed for this purpose [22]. However, these solutions are experimental in the development of power lines. Currently blasting is used in production [23].

However, in addition to the positive results of experimental studies, specific operational issues also arise, such as: What is the noise level reduction that can be achieved with the blasted surface? How does the surface behave in rain, and how the noise level varies as a function of rain intensity? How long is the drying period of the surface after the end of the rain, and how does this affect the noise of the conductor? The main issue is not only the noise of the wire of course, but also the corona radiation itself, but it is not a measurable parameter. In addition to measuring noise, measuring the radio frequency scattering gives a more complex picture.

The analysis of high voltage test results of the surface-treated conductor manufactured by FUX is presented in the article. Answers are formulated to the operational questions introduced above by evaluating the results. The design of the conductor itself, the voltage level, and environmental factors significantly impact corona radiation. So, a general answer cannot be given, but the measurement experience based on theoretical considerations describing the degree of corona radiation [24] provides applicable information.

1. MATERIALS AND METHODS

1.1. Tested conductors

The tested conductors were constructed of ACSR 339-AL1/30-ST1A structure according to EN 50182:2001. The main properties of this conductor are summarized in *Table 1*. The examination only covered the high-voltage test, no other parameters were determined during the high-voltage tests. The measured values were determined by FUX QC Laboratory.

1.2. Test methods

The test was carried out in the High-Voltage laboratory of the University of Graz led by Oliver Pischler and Tennet TSO Gmbh. In addition to the high voltage, the Laboratory could provide continuous artificial rain during the test. The conductors were tested in bundles of four which is one of the normal set-ups in high-voltage transmission. The length of the sample conductor section was 10 meters. The conductors were prepared in advance, straightened with specific end fixing, and transported to the test in crates instead of coiling on a drum. The surface of the conductor samples was protected with the packaging after production so that they are not damaged during transportation.

Table 1

The construction and properties of the tested conductors

Type	*ACSR 339-AL1/30-ST1A*	
Property	*Nominal value (EN 50182)*	*Measured value*
diameter	*25 mm*	*25 mm*
Number of Aluminium wires	*+ 10 + 16 + 22 AL1*	
Aluminium wire diameter	*3.0 mm*	*2.99–3.01 mm*
Number of steel wires	*1 + 6 ST1A*	
Steel wire diameter	*2.33 mm*	*2.33–2.34 mm*
Strand direction and strand length		
1st layer (+6 Steel)	*left, 112–182 mm*	*125 mm*
2nd layer (+10 Aluminium)	*Right, 130–208 mm*	*189 mm*
3rd layer (+16 Aluminium)	*Left, 190–304 mm*	*246 mm*
4th layer (+22 Aluminium)	*Right, 250–350 mm*	*270 mm*
Flow meter weight	*1183.4 kg/km*	*1180.6 kg/km*
Calculated tensile strength	*91.7 kN*	*93.79 kN*
DC resistance	*0.08520 Ω/km*	*0.08346 Ω/km*
Current capacity	*769 A*	

Assembly and tests were carried out at laboratory temperature without tempering. The test took a long time, so the temperature varied between 22 and 24 °C. The samples were assembled and fixed carefully so that the surface of the conductors was not damaged. After tensioning, the geometry of the bundling and the distance between the wires were checked and adjusted. The distance of the wires in the bundle was 400 m.

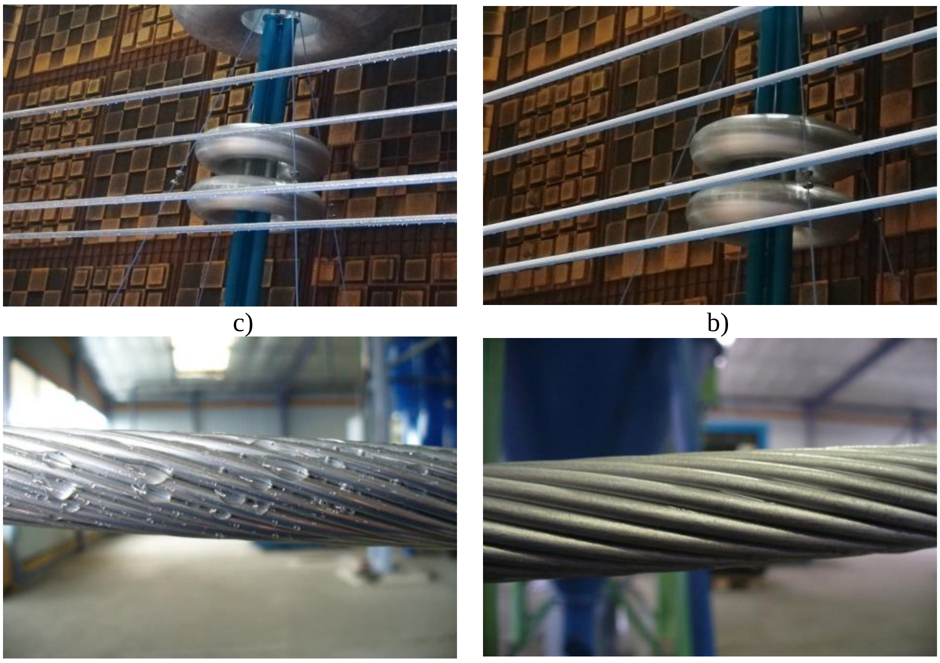
After the installation, the conductors so the whole bundle were conditioned which means switching to 300 kV for 10 minutes. During this time, dust and small impurities on the conductors were washed off the surface. During further operation, a corona-detection camera was used to search for impurities acting as scattering centres. After the voltage was switched off, the surface was wiped off with dry cloths. When the corona camera no longer showed a stable scattering centre, the cleaning was stopped, and the measurements started.

After conditioning, the conductors were loaded to specific voltage levels and the intensity of audible noise and radio frequency dispersion were measured. At each voltage level, after two minutes a steady state was reached before recording the noise level. The measurement started at 140 kV and ended at 270 kV.

Two types of tests were carried out with the wet conductors. First, the drying time and the change in noise during drying were measured. For this, the conductors were moistened with a continuous water jet. After the water was shut off, the bundles were loaded to 220 kV. At the end of the load, microphones were used to record the audible noise, and the strength of the radio frequency dispersion was also measured. The test lasted for 15 minutes.

The intensity of the rainfall was then adjusted by measuring the amount of water that fell on the area over a given period. After the rain had stabilized, the line was loaded to the same voltage levels as in the dry case. Also, the intensity of the audible noise and the radio frequency dispersion was measured in this case, too. After two minutes waiting time for at each voltage level, the steady stage was reached before recording the noise level. In this case, the measurement was also terminated at 270 kV.

Figure 1 shows the measurement setup and the droplets on the surface-treated and untreated wires. It also shows the water droplets on the surface of the conductors after the water spray test (IEC/TS 62073:2003).


c) b)

c) d)

Figure 1

Wires were assembled in the test set-up in four bundles: untreated (a), treated (b). Water spray test of untreated wire (c) and surface treated type (d).

2. RESULTS AND DISCUSSION

The noise level (L_{Aeq}) variation is given in relation to dB(A) (IEC 61672:2002). *Figure 2* compares the noise of dry conductors with the results measured with 6 mm/h of artificial rainfall. The noise of the conductor increases during sprinkler irrigation.

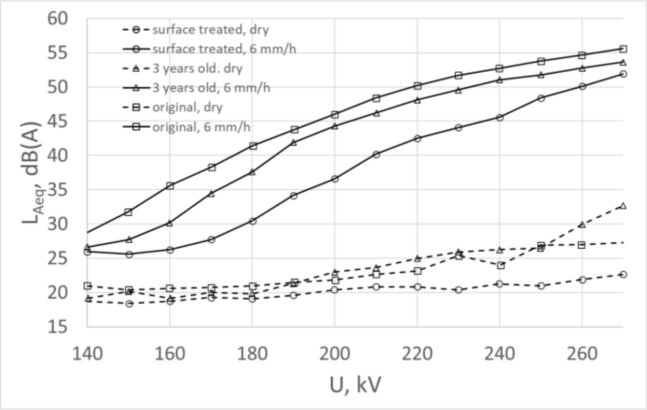


Figure 2

The change in the noise level of the dry conductors and the noise level of 6 mm/h during artificial rain

The plots show that the noise of the surface-treated conductor is the lowest even in the dry case, but a significant difference can be measured during rainfall. In all cases, noise increases as the voltage level increases, but the rate of increase is the lowest for surface-treated conductors. The noise of a conductor dismantled after 3 years of operation is also lower than that of a freshly manufactured wire without surface treatment, but much higher than that of a surface-treated wire. After three years of operation, the surface is not yet sufficiently contaminated to re-apply surface treatment. This is estimated in the literature to require 15-20 years of operation. Of course, atmospheric pollution and corrosive effects can majorly impact this.

The test was also carried out with 3.5 mm/h artificial rain. *Figure 3* compares this result with the results obtained with 6 mm/h rain. In the case of less intense rain, the noise of the lines is also lower. Even with an intensity of 3.5 mm/h, the noise of the surface-treated wire is the smallest, and the one manufactured without the surface treatment is the noisiest. It is interesting to observe that in the case of the line that has been in operation for 3 years, the change in the intensity of the rain does not bring about a significant change in noise.

When examining the drying of the wire, we examined the noise of the wetted wire at a constant voltage level (220 kV). The noise level was recorded every minute for 15 minutes *(Figure 4)*. It can be seen that the noise of the surface-treated wire is the smallest in this measurement as well, but the noise generated by the wire that has been in operation for 3 years decreases the most during drying. The noise generated by the cable produced without surface treatment is reduced to the smallest extent and remained at a high level during the entire test period.

The radio frequency dispersion (RIV) was also measured in addition to the noise level *(Figure 5)*. In the figure, the conductor produced without surface treatment and the one with surface treatment are compared. Both types of wires show similar values when dry. Due to the corona radiation during rain, just like the noise, this value also increases significantly. It can also be seen here that because of the surface treatment, just like the noise, the radio frequency scattering is also smaller. Of course, the environmental factors, in our case: the intensity of the rain also has an effect here. The more intense the rain, the more drops there are, so the standard deviation shows a higher value.

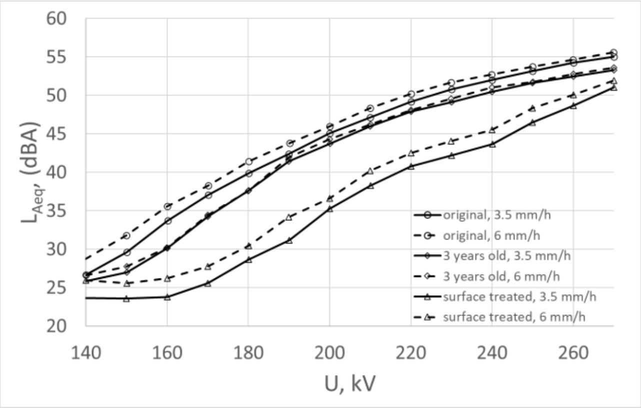


Figure 3

The noise level of the examined lines at 3.5 mm/h and 6 mm/h during artificial rain

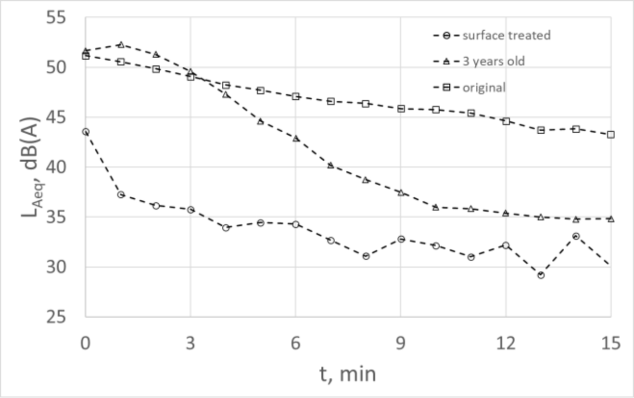


Figure 4
The change in noise during the drying of moistened wires

In the description of corona radiation, one of the earliest theories is related to the onset of corona radiation, which makes it possible to calculate an onset voltage level. The frequently used Peak's formula is an empirical calculation of the onset gradient:

$$E_c = mE_0\delta\left(1 + \frac{c_1}{\sqrt{\delta r_c}}\right) \tag{1}$$

E_c is the onset gradient in kV/cm, E_0 is an empirical constant (29.8 kV/cm), c_1 is another empirical constant (according to Peak is 0.301 $cm^{-1/2}$), m is the conductor irregularity factor, which considers the surface condition of the conductor, δ is the relative air density according to (2).

$$\delta = \frac{273+t_0}{273+t}\frac{p}{p_0} \tag{2}$$

p is the ambient pressure, p_0 is a reference pressure (1.013 bar), t is the temperature in °C, t_0 is the reference temperature (25 °C).

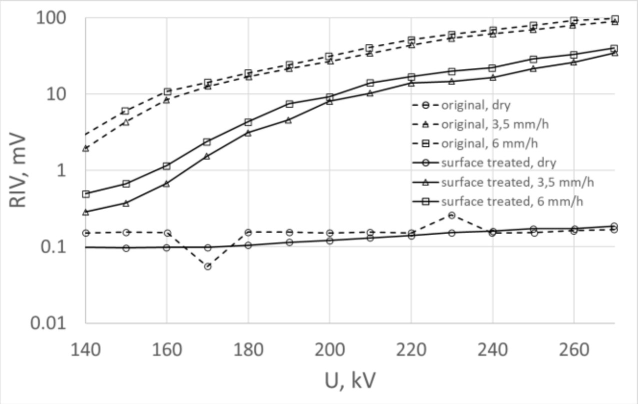


Figure 5
The change of the radio frequency dispersion as a function of increasing the voltage

Peak's formula shows that the early theory of corona radiation contains the surface condition (m) as an important factor before the development of the surface treatments. This m parameter contains the relationship between the wettability of the conductor and water quality, namely the pollution level of the atmosphere during rain. So, m is a single parameter, but it has a complex interpretation. Additionally, the size of the conductor and the bundling configuration also have large effect on the corona radiation. A single measurement is not enough to determine the exact value of m, but it is good to assume, which helps to do some prediction in given operating conditions.

CONCLUSION

In the high-voltage laboratory of the University of Graz, together with Tennet TSO Gmbh and FUX Co. examined the effect of the surface treatment of uninsulated overhead lines on the degree of the noise of corona radiation. The surface treatment method we used was blasting. ACSR 339-AL1/30-ST1A conductor with and without surface treatment was delivered to the test. Our partners dismantled a line with the same structure from a section that had been in operation for three years. During artificial rain, the noise effect was measured with dry lines, 3.5 mm/h and 6 mm/h. We compared the behavior of the wires with each other.

The measurement results showed that surface treatment can significantly reduce the noise caused by corona radiation. Of course, this is affected by the intensity of the rain. In a rain of greater intensity, we measured a greater noise load. It was observed that in the case of the three-year-old line, the consequences of the operation reduced the noise effect, but the noise was closer to the line without surface treatment. This operating time was not sufficient for the reduction of corona radiation mentioned in the literature.

Of course, the surface treatment does not only reduce the level of noise, but also the level of all the phenomena created by corona radiation, which was demonstrated through the measurement of radio frequency scattering. The series of measurements supported the experience so far, according to which the wire surface treated with grain spraying performs well in reducing the noise effect caused by corona radiation and other effects.

ACKNOWLEDGMENT

The tests are supported by Tennet TSO Gmbh and the High Voltage Laboratory of the University of Graz. The development program especially thanks Oliver Pischler for his professional help. M. Sepsi contributed with the professional support of the Doctoral Student Scholarship Program of the Co-operative Doctoral Program of the Ministry of Innovation and Technology financed by the National Research, Development, and Innovation Fund.

REFERENCES

[1] J. R. Davis (ed.): *Aluminum and Aluminum Alloys.* ASM Specialty Handbook. ASM International, 1993.

[2] B. Stojanovic, M. Bukvic, I. Epler: Application of Aluminum and Aluminum Alloys in Engineering. *Applied Engineering Letters*, Vol. 3 (2), pp. 52–62, 2018. https://doi.org/10.18485/aeletters.2018.3.2.2

[3] G. E. Totten, D. S. MacKenzie (ed.): *Handbook of Aluminum.* Basel: Marcel Dekker Inc., 2003.

[4] L. Kirkpatrick (ed.): *Aluminum Electrical Conductor Handbook*. Washington: The Aluminum Association, 1989.

[5] S. P. Kumar, R. Parameshwaran, S. A. Kumar, S. Nathiya, K. Heenalisha: Electrical and mechanical studies on pure-silver coated aluminum based electrical contact materials. *Materialstoday: Proceedings*, Vol. 33 (7), pp. 3621–3625, 2020. https://doi.org/10.1016/j.matpr.2020.05.666

[6] Sz. Gyöngyösi, A. Gábora, G Balogh, G. Kalácska, T. Bubonyi, T Mankovits: Effects of Additives on the Mechanical Properties of Aluminum Foams. *Mechanisms and Machine Science*, Vol. 109, pp. 307–313, 2022. https://doi.org/10.1007/978-3-030-88465-9_28

[7] G. Langelandsvik, T. Furu, O. Reiso, H. J. Roven: Effects of Iron Precipitation and Novel Metal Screw Extrusion on Electrical Conductivity and Properties of AA1370 Aluminium, Materials Science and Engineering: B, vol. 254, pp. 1-8., 2020. https://doi.org/10.1016/j.mseb.2020.114505

[8] S. L. Cai, J. C. Wan, Y. J. Hao, C. C. Koch: Dual Gradient Microstructure to Simultaneously Improve Strength and Electrical Conductivity of Aluminum Wire. *Materials Science and Engineering: A*, Vol. 783, pp. 1–14, 2020. https://doi.org/10.1016/j.msea.2020.139308

[9] Konstatin O. Papailiou (ed.): *Overhead Lines*. Cigré Green Books. Springer, 2017.

[10] P. Koprowski, M. Lech-Grega, Ł. Wodziński, B. Augustyn, S. Boczkal, M. Ożóg, P. Uliasz, J. Żelechowski, W. Szymański: The Effect of Low Content Additives on Strength, Resistivity and Microstructural Changes in Wire Drawing of 1xxx Series Aluminium Alloys for Electrical Purposes. *Materialstoday Communications*, Vol. 24, pp. 1–12, 2020.

[11] CTC Global: *Engineering Transmission Lines with High Capacity Low Sag ACCC Conductors*. Engineering Manual. CTC Global, 2011.

[12] S. Wan, H. Zhou, L. Li, C. Wang, M. De Filippo, Fan Gong: Degradation of artificially corroded galvanized high-strength steel wires: Corrosion morphology and mechanical behavior. *Construction and Building Materials*, Vol. 346, 2022. https://doi.org/10.1016/j.conbuildmat.2022.128387

[13] L. Daróczi, Sz. Gyöngyösi, L. Z. Tóth, D. L. Beke: Effect of the martensite twin structure on the deformation induced magnetic avalanches in Ni2MnGa single crystalline samples. *Scripta Materialia*, Vol. 114, pp. 161–164, 2016. https://doi.org/10.1016/j.scriptamat.2015.12.018

[14] L. Q. Khai, H. S. Lee: Efficiency Assessment of Technologies Implementation in Vietnam Power Transmission System. *Energy Reports*, Vol. 8 (3), pp. 16–22, 2022. https://doi.org/10.1016/j.egyr.2022.01.026

[15] Z. Engel, T. Wszolek: Audible Noise of Transmission Lines Caused by the Corona Effect: Analysis, Modelling, Prediction. *Applied Acoustics*, Vol. 47 (2), pp. 149–163, 1996, https://doi.org/10.1016/0003-682X(95)00041-7

[16] B. Wan, W. He, C. Pei, X. Wu, Y. Chen, Y. Zhang, L. Lan: Audible Noise Performance of Conductor Bundles Based on Cage Test Results and Comparison with Long Term Data. *Energies*, 10, pp. 1–12, 2017, https://doi.org/10.3390/en10070958.

[17] James C. Matthews: The effect of weather on corona ion emission from AC high voltage power lines. *Atmospheric Research*, Vol. 113, pp. 68–79, 2012. https://doi.org/10.1016/j.atmosres.2012.03.016

[18] N. Ali, J. A. Teixeira, A. Addali, F. Al-Zubi, E. Shaban, I. Behbehani: The effect of aluminum nanocoating and water pH value on the wettability behavior of an aluminum surface. *Applied Surface Science*, Vol. 443, pp. 24–30, 2018. https://doi.org/10.1016/j.apsusc.2018.02.182

[19] D. E. Selvaraj, K. Mohanadasse, C. P. Sugumaran, R. Vijayaraj: Application of Nano Coating to ACSR conductor for the Protection of Transmission lines against Solar Storms, Surface Flashovers, Corona and Overvoltages. *J. Electr. Eng. Technol.*, Vol. 10 (5), pp. 2070–2076, 2015, https://doi.org/10.5370/JEET.2015.10.5.2070

[20] K. A. Emelyanenko, A. G. Domantovsky, P. S. Platonov, P. S. Kochenkov, A. M. Emelyanenko, L. B. Boinovich: The Durability of Superhydrophobic and Slippery Liquid Infused Porous Surface Coatings under Corona Discharge Characteristic of the Operation of High Voltage Power Transmission Lines. *Energy Reports*, Vol. 8, pp. 6837–6844, 2022, https://doi.org/10.1016/j.egyr.2022.05.035

[21] R. L. Kovács, G. Langer, Sz. Gyöngyösi, Z. Erdélyi: A Versatile Technique for In-situ Investigation of the Effect of Thin Film Cracking on Gas Permeation of Coated Flexible Polymers. *Review of Scientific Instruments*, Vol. 92, pp. 1–4, 2021. https://doi.org/10.1063/5.0028783

[22] P. Barkóczy, A. E. Benchabane, Sz. Gyöngyösi, L. Juhász, T. Kaselov, U. Dawidowski: Mechanical behivor of a titanium-oxide layer on aluminium wires during conductor manufacturing. In: G. Szabó, M. Szűcs (eds.): *XVI. Képlékenyalakító Konferencia*, Miskolci Egyetem, Műszaki Anyagtudományi Kar, pp. 81–85, 2018.

[23] A. E. Benchabane, P. Barkóczy: Effects of surface treating to the properties or railway contact wires. In: S. Bodzás, T Mankovits (eds.): *Proceedings of the 5th International Scientific Conference on Advances in Mechanical Engineering (ISCAME 2017)*, Debrecen, University of Debrecen Faculty of Engineering, p. 650, 2017.

[24] K. Tonmitr, T. Ratanabuntha: Comparison of power loss due to corona phenomena model with Peek’s formula in high voltage 115 kV and 230 kV system. *Procedia Computer Science*, Vol. 86, pp. 385–388, 2016. https://doi.org/10.1016/j.procs.2016.05.037