COMPUTER-AIDED SIMULATION FOR DEVELOPMENT AND MANUFACTURE OF PLASTICALLY CRIMPED CONDUCTORS AND DESIGN OF TRANSMISSION LINES

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This article describes the results of applying computer-aided simulation at all stages of creation of plastically crimped conductors used in overhead transmission lines, including optimization of the conductor design to achieve the service properties required by consumers and to determine the technological parameters of production. Computer-aided simulation allows reducing the time of designing and the cost of experimental works in respect of the manufacture and certification of conductors.

Keywords: computer-aided simulation; finite element method; plastically crimped conductors; deformation; conductors for high-speed lines; design; strength; modulus of elasticity.

Innovative products
for infrastructure project
developed by LLC Energoservice

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INTRODUCTION

Plastic crimping of helical conductors with linear contact of wires between adjacent layers yields better mechanical, aerodynamic and operational properties (higher strength, modulus of elasticity and self-extinguishment of oscillations, reduced load from wind pressure and ice coating) owing to denser grooming of wires in the conductors and a smoothened surface profile [1-2]. Specialists of LLC Energoservice (Moscow) and Ltd Metsbytservis (Moscow) have designed plastically crimped ground wires [3-5], steel reinforced aluminum conductors (ACSR) [6], and copper and copper-clad steel conductors [7, 8] for overhead transmission lines (OHTL), with their manufacturing technology mastered by the Volgograd branch of AO Severstal Wire Ropes (City of Volgograd). Non-insulated high-strength (ASHS) and high-temperature (ASHT) steel reinforced aluminum conductors [9] were designed in order to improve the cost-effectiveness and operational reliability of installation and reconstruction of high and ultra-high voltage overhead transmission lines. Their economic effect in the reconstruction of 35 to 750 kV power networks is achieved by increasing the network capacity, improving the reliability of power supply, and reducing the conductor heat and corona losses (during the comparative tests on the conductors of identical diameter at the HV EMC test laboratory of JSC R&D Center at FGC UES, owing to the smoothened profile, the corona start voltage of an ASHS conductor per STO 71915393-TU 120 2013 was 5.7 % higher than for an AS conductor per GOST 839-80). On the basis of the performance tests carried out in a specialized organization, the MK-type plastically deformed copper catenary wire was recommended for the electrification and power supply of JSCo RZD.

COMPUTER-AIDED SIMULATION IN OPTIMIZATION OF CONDUCTOR DESIGN

Thanks to a deeper understanding of the physical processes occurring in the manufacture and operation of conductors, computer-aided simulation allowed optimization of their design with regard to consumer demands and reduction of the labor input of their implementation by:

- optimizing the geometry of OPGW strands and technological parameters of plastic deformation that ensure integrity of the optical module [10];
- establishing the distribution of temperature fields across the OPGW section with differing duration and amperage of a short circuit current [11] and the magnitudes of electromagnetic effects with alternating current in steel reinforced aluminum conductors of the ASHS type, which has shown that the direction of a layer of aluminum strands with an even number of layers has virtually no impact on the heat release in the steel core provided that reliable electrical contacts are formed between the strands by plastic crimping [12];
- demonstrating the possibility to further reduce the dimensions

ULTIMATE TENSION FORCES FOR A COPPER-CLAD STEEL CONDUCTOR: 1 TO 4 ARE RESPECTIVELY FOR MK HSL-4; MK-HSL-4-A; MK-HSL-4-B; MK-HSL-4-C

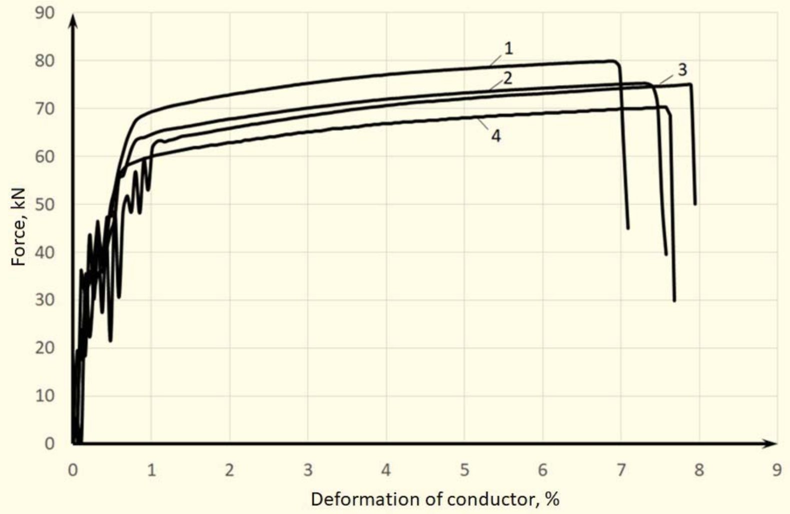
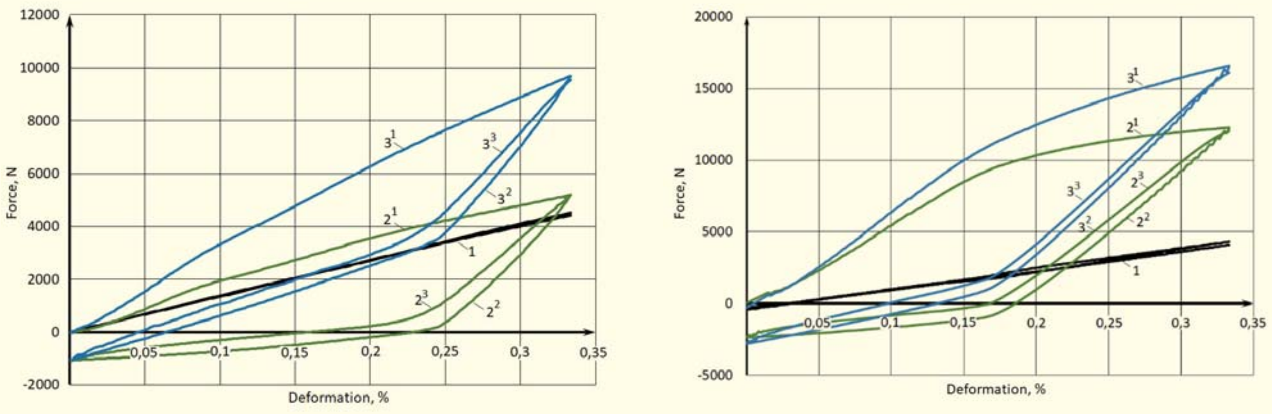


Fig. 1

VARIATION OF FORCES ALONG THE AXIS IN THE ELEMENTS OF COPPER-CLAD STEEL UNCRIMPED (A) WIRE AND AFTER CRIMPING (B)



a) b)

1^1, 1^2 and 1^3 — in central steel strand; 2^1, 2^2 and 2^3 — total force in copper strands; 3^1, 3^2 and 3^3 — total force in steel and copper strands; 1^1, 2^1 and 3^1 — pre-stretch; 1^2, 2^2 and 3^2 — compression to initial length; 1^3, 2^3 and 3^3 — ultimate tension

Fig. 2

of ACSR conductors by using an already twisted conductor before plastic deformation and by applying pre-crimping of the steel core. The new design of the plastically crimped, high-strength metal core has made it possible to increase the core strength by 35 % to 45 % and reduce the nominal conductor diameter with similar cross-section areas of the conductive part as compared with the ACSR conductor per GOST 839-80 and, as a result, to decrease the tower loads caused by the conductor weight and wind-induced vibration [15].

- developing a method for evaluation of the impact of wind load on OHTL conductors of different designs using computer-aided simulation of air flowing with a specific velocity through the space with a conductor located within based on the Navier-Stokes equation. Simulation at different air stream velocities typical for wind zones I and III and a special wind zone as per PUE-7 has shown that the wind pressure on a plastically crimped ASHS conductor is 25 % to 40 % lower than the wind pressure on standard AS conductors with a comparable current-carrying capacity [13]. The smoother contour and smaller diameter of ASHS conductors effectively reduce the dead zone behind the conductor and the higher pressure zone before the conductor. The wind load on ASHS conductors with a more streamlined geometry is on average 33 % lower, which allows minimizing stress on the transmission line towers and mounting higher capacity conductors during overhauls on the existing towers.

One of the latest advancements in the utilization of FEM is the creation of a copper-clad steel catenary and contact wires of high-speed lines (HSL) for the railway transport. The main requirements to a catenary are higher tension and, respectively, higher mechanical strength of contact wires and carrier wires, thermal and wear resistance, minimized weight of all structural elements with stricter requirements to their strength and durability, and reliable protection of those elements from corrosion for the whole period of service. Copper or bronze conductors are utilized in Russia and abroad in catenaries (bimetallic conductors can also be used). Application of the finite-element modeling methods of computer simulation [14] has allowed, through an optimized design of plastically crimped carrying and contact conductors made from steel core copper wires, increasing the carrying capacity of the conductor to ensure the necessary rupture strength in the specified dimensions. During the tension test of plastically crimped ø14 mm copper-clad steel wires in a specialized organization of JSC VNIIZHT, the breaking force was equal to 80.6 kN. The carrier wire design is protected by Russian utility patent No. 171205 [9].

The utilization of FEM allows optimizing the MK-type conductor design to meet the specific needs of the designers of catenaries of different high-speed lines. For example, for the KS-400 catenary of HSL-2 Moscow-Kazan, special requirements apply to the wave propagation velocities on the catenary and carrier wire to ensure the necessary quality of current collection across the whole range of travel speeds up to 400 km/h. Oscillatory and wave effects in the catenary leading to poor current collection play a significant part in the process of dynamic interaction between the current collector and catenary as travel speed increases. The shear wave velocity on catenary conductors, which decreases as the bulk weight increases, should be about 1.5 times greater than the current collector travel speed. The calculation shows that for a catenary with the HSL-4 MK wire tested at JSC VNIIZHT the maximum travel speed of electrified rolling stock should not exceed 393.26 km/h, and for the HSL-4 MK carrier wire — 372.57 km/h. The reason is that the bulk weight of the HSL-4 MK wire is 17 % to 21 % higher than that of less strong wires JMH-120, Br2F 120, and CuNb-120, which are recommended for use in the KS-400 project. To reduce the bulk weight, variants of HSL-4 MK wires were used with a reduced cross-section area of copper strands of the outer layers, which led to reduction of the plastically crimped wire diameter from 14 mm to 13.6 mm. As the finite-element modeling has shown, the change in the wire design led to some reduction in the estimated rupture force (Fig. 1), which, however, satisfied the minimum requirements for the carrier wires and contact wires of the KS-400 catenary of HSL-2 Moscow-Kazan (67.6 kN) in all of the simulated variants.

The FEM allows, as early as at the designing stage, determining the modulus of elasticity of conductors consisting of multiple strands with heterogeneous chemical composition and different twist options, which is an important operational characteristic that largely determines the sag of conductors at different tensions. For example, Fig. 2 illustrates the behavior in the elastic-plastic area of the copper-clad steel carrier wire before and after crimping at simulation of pre-stretching, compression to initial length, and re-stretching. Plastic crimping resulted in reduction of the wire elongation almost 1.5 times compared with the traditional wire stretched with the same stresses. The average corrected modulus of elasticity was about 23 GPa while pre-stretching an uncrimped wire and 39 GPa after plastic crimping.

CONCLUSIONS

The utilization of finite-element simulation allowed creating a system of online designing of conductors as required by the operating organizations. Their applicability was verified by experimental studies of products in certified organizations of PJSC ROSSETI and JSCo RZD that confirmed the estimated characteristics of the products and accuracy of the models

The long-term set of works allows demonstrating in a separate case study the possibility of applying digital technologies at all stages, from product development and testing to design and implementation.

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