Compact messenger cable solutions for high-speed rail lines

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Overhead catenary systems installed on high-speed lines possess a number of unique characteristics that ensure safe and smooth train operation. This includes the increased tension of a contact wire, messenger cables and connecting wires; thermal endurance and wear resistance; increased mechanical strength of contact wires and cables; minimal mass of all structural elements but not at the expense of strength and durability; and reliable rust protection. To satisfy these stringent requirements, Ø 120-150mm2 low alloy copper or bronze contact wires are traditionally used. The contact wire shall have minimum sag, which is ensured by an overhead catenary system that uses closely spaced droppers to attach the messenger wire or catenary to the contact wire.

Innovative MK-series messenger wire

Russian engineers have created a wire that is ideally suited for batch production while offering high strength, slight temperature-related linear deformation, good rust resistance, electrical conductivity which is close to copper conductors, and enhanced aerodynamic properties. The wires have standard dimensions and are compatible with standard fittings. MK-series compact and plastically-deformed messenger wires may also be used as auxiliary messenger wires, electric connectors between contact wire and feeder line wires.

This copper catenary alloy-free wire solution is a breakthrough in that it offers high strength without the traditional drawbacks of alloy-based solutions. Advantages include:

- reduced amplitude and strength of wire dancing;
- reduced risk of wire break;
- low stress in the event of snow and ice accumulation due to the smooth exterior shape;
- high-strength parameters which are close to the performance of bronze wires;
- high current-carrying capacity and electrical conductivity, and;
- enhanced aerodynamic parameters.

Russian Railways (RZD) and the Russian R&D Institute of Rail Transport (VNIIZhT) have conducted comprehensive tests of the MK compacted copper messenger wire, which demonstrated that pressed wires provide an enhanced cross-section utilisation ratio, reduced electric impedance in the traction network, improved load-carrying capacity and better thermal resistance. An extensive testing programme checked the factors which may affect the catenary wire in real life but at the possible extremes of performance. This included a thermal degradation check with heating to 155°C, track resistance tests, bending tests, low-temperature creeping tests, endurance to vertical oscillations (eolian vibration) with multiple heating to 100°C, and other tests, some of which have never been performed for catenary wires before.

As part of RZD's Resource-Saving Technologies Deployment Programme, the MK-120 series compacted wire was installed as pilot messenger wire in 2015 and 2016 on track sections totalling 60km on the West Siberian Railway and South Urals Railway. The MK-120 wires were installed according to a traditional installation process using existing fittings and tools and the tests showed that the wire's catenary impedance reduction would offer an economic benefit to the railway.

Following a meeting of the Innovative Technologies Working Group of the Russian Ministry of Transport in September 2016, it was recommended that state-owned companies purchase MK-series messenger wires. In 2017, the MK-120 compacted wires were installed on sections of the Sverdlovsk Railway, South Urals Railway and West Siberian Railway for a total length of 109.4km.

The remainder of this article describes the results of the efforts to optimise the design of these plastically pressed copper-clad steel messenger and contact wires through finite element design methods with the goal of acquiring the required tensile strength at given dimensions.

Plastic deformation of a system consisting of elements with vastly different mechanical properties were based on the careful and correct identification of methods to achieve optimal geometry, design and process-dependent analyses of wire strands as well as their related technological parameters. This is important as the resulting deformation of the elements may be either excessive or not appear at all. Using traditional empirical methods to change to new wire sizes and testing the prototype wire's strength parameters is both a time consuming and resource-intensive process. Using computer-based simulations of wire pressing and their tensile behavior was therefore considered appropriate for the preliminary capturing of performance data relating to advanced design of the alternative wire.

Methods of research

A wire featuring a central steel core and three copper layers (see case A in Table 1) of 1+7+7/7+14 configuration with an outside diameter of about 14mm was used as a reference case. Plastic deformation simulation was carried out with the use of SIMULIA/Abaqus software suit. The plastic deformation simulation included pulling the stranded wire system through four pressing rollers. Following the pressing process, clamping jaws at wire ends were moved apart at 2 mm/s with resulting force tracing.

Table 1. Configurations of copper-covered steel wires used in simulations

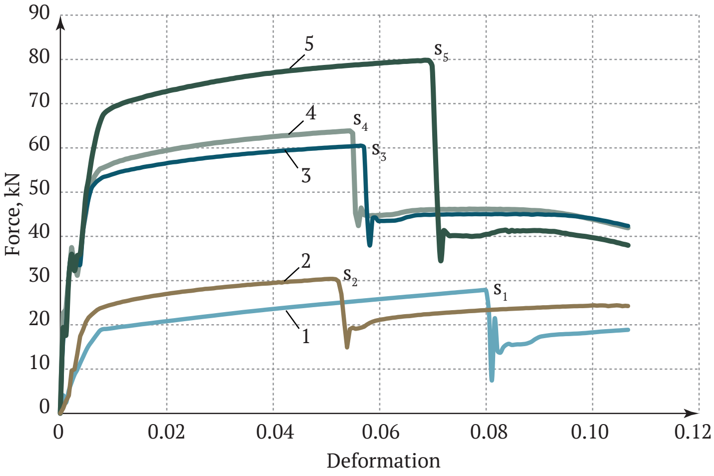
Case	Strand dimension and material				Copper/steel area
	Core	1st layer	2nd layer	3rd layer	
A Non-pressed	Steel 1×ø29mm	Copper 7×ø 21mm	Copper 7×ø2.05mm+7 ø1.45	Copper 14×ø2.55mm	130.4/6.61mm^2
B pressed	Steel 1×ø2.9mm	Copper 7×ø 2.1mm	Copper 7×ø2.05mm+7 ø1.45	Copper 14×ø2.55mm	130.4/6.61mm^2
C pressed	Steel 3×ø2.0mm	Copper 6×ø 2.1mm	Copper 14×ø1.8mm	Copper 14×ø2.55 mm	127.9/9.42mm^2
D pressed	Copper 1×ø2.9mm	Copper 4×ø2.15mm Steel 3×ø2.15mm	Copper 7×ø2.05mm 7×ø1.63mm	Copper 14×ø2.65mm	136.1/10.89mm^2
E pressed	Steel 1×ø2.9mm	Copper 4×ø2.15mm Steel 3×ø2.15mm	Copper 7×ø2.05mm 3×ø1.63mm	Copper 14×ø2.65mm	129.4/17.5mm^2

Results and findings

When tension is applied to a wire that is plastically pressed, the major load is carried by the central steel wire (see Figure 1). Copper wire tension causes pitch extension while at the same time the stresses grow slower. Copper wire's contribution to overall strength characteristics is therefore rather small. Following a steel core rupture at ca 25kN, the copper layers undertake a major load but cannot ensure the required breaking force (about 70kN) without the steel element.

Wire plastic pressing (see case B) has slightly improved the performance of core steel wire and stranded copper wires due to friction forces. However, the solution does not offer more than a 30kN strength improvement (Fig. 1, curve 2).

For case C, the steel and copper system included three core stranded steel wires with a smaller diameter instead of one steel element, with the steel wire's pitch coinciding with copper wire's pitch. This configuration helped to increase the break-



Legend: Sn – steel core breaking point for cases A through D

Fig. 1. Tensile breaking loads applied to copper-clad steel wire. Curves 1 to 5 refer to A to D cases respectively

ing tension to 60kN (see Figure 1, curve 3) without changing the ratio between the steel and copper layer cross sections.

The best breaking tension results were received in case E, which comprised one core steel wire and three steel wires in first layer. The configuration led to a slight reduction of the copper wire's cross section (see Table 1), but the estimated breaking tension value reached as much as 80kN.

According to the results from the E case during the tests carried out by VNIIZhT, the breaking tension of the ø14mm plastically-pressed copper-clad steel catenary wires was even better at 80.6kN. The design and manufacturing process of the catenary wire and its modifications are covered by German and Russian patents.

It is noteworthy that the MK wires have substantially better tensile strength and continuous current performance than messenger wires of a comparable diameter under DIN 48201 (Table 2).

MK wires' high performance characteristics offer significant opportunities for application not only in Russia but around the world. In order to reach the standards required for international applications, work was initiated at the International Electrotechnical Commission (IEC). In 2015, the TC 9 Dashboard of the IEC General Assembly decided to create a working group to prepare the releavant standards, a unique case for a Russian initiative supported by the IEC. In addition, the initiative was backed by experts from 10 countries, including Germany and Japan.

The preliminary Working Group AHG 14, which drafted the content for the standards, was transformed into permanent Working Group PT 63190 on March 20th 2018. The working group will develop the standard, fulfil the technical element and secure consensus-based approval by integrating the comments and requirements of the members. The working group's membership has since grown with the addition of French and British experts.

Table 2. Comparison of MK copper messenger wire, two copper clad steel messenger wires (MK-HS-1 and MK-HS-4) and bronze catenary wires under DIN 48201

Rated area (mm^2)	Actual cross-section area (mm^2)	Diameter (mm^2)	Weight (kg/km)	Breaking tension (kN)			Continuous current, A		
				Bz I	Bz II	Bz III	Bz I	Bz II	Bz III
70 DIN	65.81	10.5	596	32.51	38.64	44.14	285	245	175
MK 70	83.4	10.7	780	32.94			366*		
MK70-HS-1	83.4	10.7	774		35.3			347	
MK70-HS-4	83.4	10.7	766			44.2			343
120 DIN	116.99	14	1,060	56.68	67.57	77.46	410	350	250
MK 120	138.7	14	1,300	55.6*			511*		
MK120-HS-1	138.7	14	1,281		69.56			501	
MK120-HS-4	138.7	14	1,108			80.6			473
150 DIN	147.11	15.8	1,337	72.67	86.37	98.67	470	410	290
MK150	182.2	15.8	1,690	72.26			612*		
MK150-HS-1	182.2	15.8	1,678.3		78.6			577	
MK150-HS-4	182.2	15.8	1,658			97.8			572

* Assumptions for current calculation: air temperature 35°C, wire temperature 70°C, crosswind – 0.6m/s