ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2024-22-1-2

World of Transport and Transportation, 2024, Vol. 22, Iss. 1 (110), pp. 163–169

Determining Mechanical Strength of Composite Traverse for 6-10 kV Overhead Power Line with Finite Element Method

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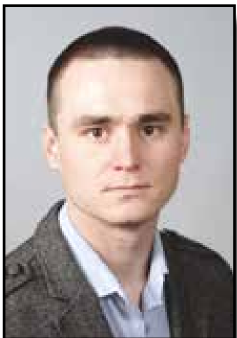

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ABSTRACT

Overhead power lines with a voltage of 6–10 kV, intended for power supply of signalling, centralised traffic control and signalling block systems and of electrical equipment along the railways use as supporting structures metallic traverses with porcelain or glass insulators. According to available data, defects caused by mechanical stresses account for more than half of the total number of disruptions in the normal operation of overhead power lines. It is worth highlighting defects that are the most frequent: chip of the insulator, bend of the pin, fracture of the pin, destruction of the insulator, separation of the insulator from the pin, distortion of the traverse, destruction of the traverse, bending of the traverse, decay or corrosion of the traverse.

To increase the reliability of overhead power lines and reduce these damages, it is proposed to manufacture traverses from polymer composite electrical insulating material. Such traverses do not have insulators and are used as an electromechanical structure with the required mechanical and electrical strength.

The objective of this work is to assess the mechanical strength of traverses made of polymer composite electrical insulating materials. To solve the set tasks, the work considers a three-dimensional model of the traverse. Its mechanical strength is determined using applied software implementing the finite element method (FEM). Loads in horizontal and vertical planes are applied to the cross-arm, the most stress-strained state of the traverse's arms and the pin bracket is determined.

In addition, the article compares the calculation results using the analytical method performed in the previous work with FEM calculation, verifies the assumed physical and geometric parameters, material properties and assumptions in calculations.

Keywords: *railway transport, power supply, traverse, crossarm, polymer composite material, mechanical strength, round crossarm (rod), load, finite element method.*

For citation: *Kochunov, Yu. A., Egorov, D. V. Determining Mechanical Strength of Composite Traverse for 6–10 kV Overhead Power Line with Finite Element Method. World of Transport and Transportation, 2024, Vol. 22, Iss. 1 (110), pp. 163–169. DOI: https://doi.org/10.30932/1992-3252-2024-22-1-2.*

The original text of the article in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

Electric power supply to railways is a complex, multi-element system, which, according to dependability criteria, is a consumer of the first category. Besides feeding electrified train traction, power is supplied to non-traction consumers, such as signalling, centralised traffic control and signalling block systems and to electrical equipment along the railways, which are powered via an overhead power line (OHL) with a voltage of 6–10 kV. Metal traverses (crossarms) with porcelain or glass insulators have been commonly used as cable bearing structures. According to statistics, defects caused by mechanical stress account for 58 % of the total number of OHL failures [1; 2].

To increase dependability and to reduce these damages, engineers of LLC «NPP ELEKTROMASH» and researchers at the Department of Transport Electric Power Supply of Ural State University of Railway Transport have developed insulating and supporting structural elements, namely brackets and traverses made of polymer composite electrical insulating material (PCEIM) [1–8].

Such structural elements have the required mechanical and electrical strength and do not have insulators, thereby reducing the likelihood of failures due to mechanical damage.

One of the stages of introducing new equipment is modelling the processes applied to the object under study. The validity of the research results must be verified by using various calculation methods and full-scale experiments. The paper [8] describes the results of calculating the mechanical strength of a PCEIM traverse using the analytical method. The calculations considered load factors, identified the most stressed structural elements when applying an acting force, and resulted in obtaining the values of stress and strain.

This present article describes the results of the second stage of the research on the mechanical strength of the PCEIM traverse using applied software that implements the finite element method (FEM).

RESULTS

The work examines a TK-3sh-BOREL [triangular] traverse as a typical sample representing PCEIM traverses (hereinafter referred to as the traverse), manufactured by LLC «NPP ELEKTROMASH» (Yekaterinburg). The main physical and geometric parameters of the traverse and its attachment points are presented in [8].

The three-dimensional geometric model of the traverse (Pic. 1) is built as a set of mechanically contacting elastic-deformable solids, considering the plastic properties of fiberglass, and also includes fastening elements in the design diagram.

The traverse (Pic. 1), as a supporting mechanical structure, is calculated using the method of three limit states [1; 8; 9]:

1. Structural strength.
2. Deformation.
3. Stability.

Using analytical calculation methods in the paper [8], it was determined that the most loaded stress-strain state (SSS) occurs when a load is applied to PSC in the horizontal plane. The design model is shown in Pic. 2.

A number of assumptions are introduced in the calculation [9–15]: CPM is modelled as two bolts anchored at the free ends (B, F); a model of contact between the 75×75×8 angle bar and the pole was chosen in which there is no friction between the surfaces [11]; bracket has restraints on movement in all directions at the free edges (not shown in Pic. 2); the pole is modelled as an absolutely rigid body with limited movement in all directions (G).

The traverse is loaded in two stages.

At the first stage, bolt tightening is simulated. The tightening force is determined by the formula:

$$Q_{tight} = \frac{\sigma_m}{\sqrt{\left(\frac{4}{\pi \cdot d^2}\right)^2 + 3\left(\frac{0{,}15}{0{,}2 \cdot d^2}\right)^2}}, \qquad (1)$$

where d is bolt diameter.

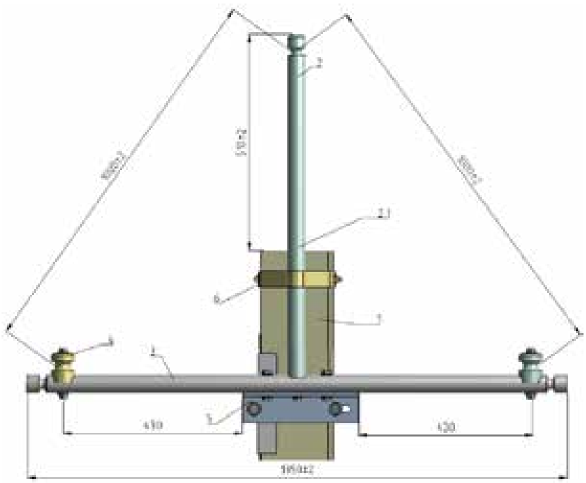
It should be noted that the tightening force applied to the bolts securing the angle bar to the pole (E, I) is taken from the strength condition of the 75×75×8 angle bar.

At the second stage, a force equal to 3 kN (A) is applied to PSC in the horizontal direction.

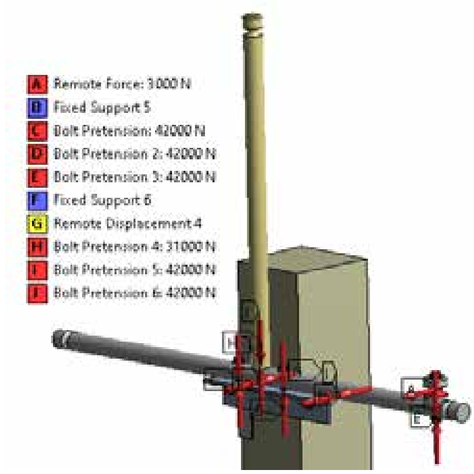
The general deformed state for the traverse for the SV-110–5 pole (design option for angle bar No. 1 as shown in Pic. 3 [8]) is shown in Pic. 3.

The distribution of equivalent von Mises stress values, MPa, of all elements of the traverse is shown in Pic. 4.

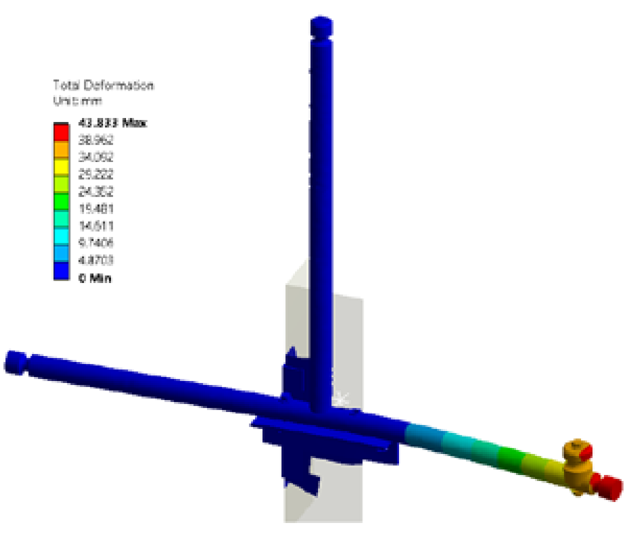
The distribution of equivalent stress values in individual elements of the traverse according to von Mises, MPa, is summarised in Table 1.



Pic.1. *Three-dimensional geometric model of the TK-3sh BOREL traverse [performed by the authors]:*
1 – pole SV-110–5; 2 – vertical traverse beam (VTB); 2.1 – restrictive groove;
3 – horizontal traverse beam (HTB); 4 – pin's spool-shaped cap (PSC); 5 – crossarm-to-pole mounting (CPM); 6 – bracket (B).



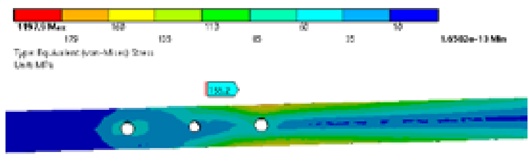
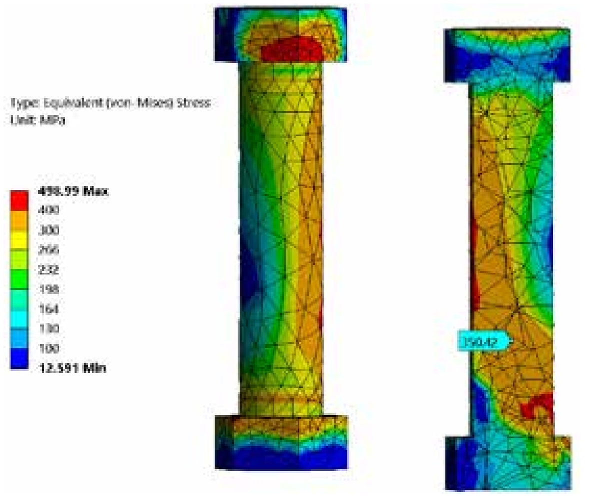
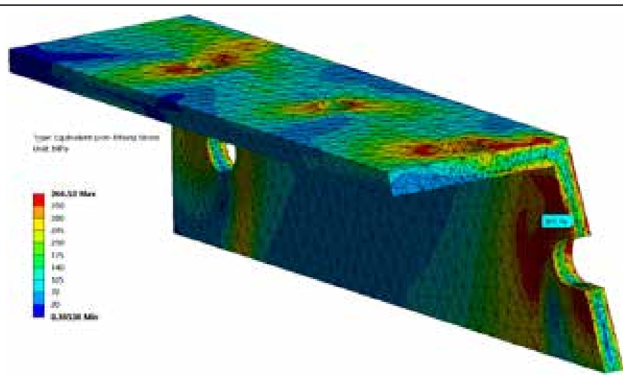
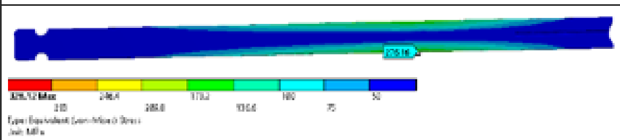
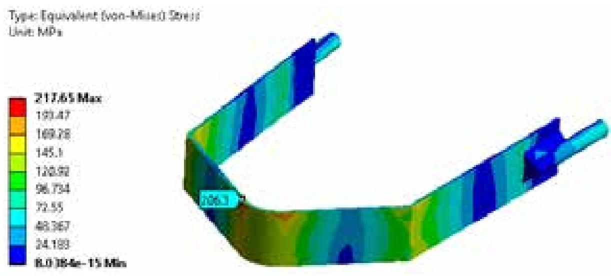
Pic. 2. Design model when load is applied to PSC in the horizontal plane [developed by the authors]: A – (force) load applied in the horizontal direction to the PSC in the area where the wire is fastened; B, F – (anchorage) free edges of CPM bolts; C, D, E, H, I, J – (axial tightening force) bolted connections; G – (limitation of movements in all directions) reverse side of the pole.



Pic. 3. General deformed state [developed by the authors].

Table 1

Results of FEM calculation for composite traverse

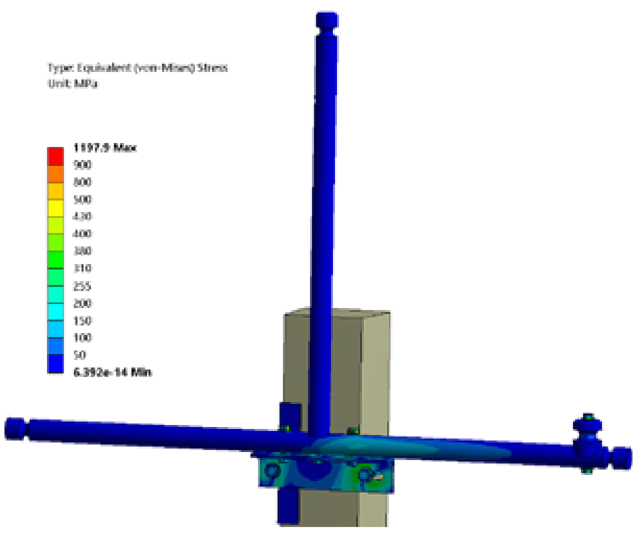
Name of the individual element of the traverse	Distribution of equivalent von Mises stress values	Maximum equivalent stress, MPa	Safety margin η
HTB (longitudinal section)		155,2*	4,4
Bolts used to secure HTB to metal 75×75×8 angle bar (section of the bolt closer to the applied load)		350,42	1,4
75×75×8 angle bar (section of the hole closer to the applied load)		301,76	2,1
HTB (longitudinal section)**		276,16	4,5
B**		206,3	2,1

*The maximum stresses in HTB, equal to 1197,9 MPa, are due to the edge effect that occurs after tightening the bolts.
** For design model No 4 [8].

Table 2

Comparative data obtained by analytical calculation method and FEM

Design model No 1				
Method	Estimated values			
	Deformation of HTB, mm	Stress of HTB, MPa	Stress of angle bar, MPa	Stress of bolts, MPa
Analytical	34,4	130,2	221,4	105,3
FEM	39,6	147,1	209,8	99,2
Error, %	13,1	11,5	5,5	6,1
Design scheme No 2				
Method	Estimated values			
	Deformation of HTB, mm	Stress of HTB, MPa	Stress of angle bar, MPa	Stress of bolts, MPa
Analytical	35,1	133,3	258,3	266,7
FEM	39,9	150,8	247,9	254,5
Error, %	12	11,6	4,2	4,7
Design model No 3				
Method	Estimated values			
	Deformation of HTB, mm	Stress of HTB, MPa	Stress of angle bar, MPa	Stress of bolts, MPa
Analytical	38,2	135,6	308,2	363,6
FEM	43,8	155,2	301,76	350,42
Relative error, %	12,7	12,6	2,1	3,8
Design model No 4				
Method	Estimated values			
	Deformation of VTB, mm	Stress of VTB, MPa	Stresses of B, MPa	
Analytical	35,6	285,7	221,4	
FEM	39,5	276,16	206,3	
Error, %	9,9	3,5	7,3	



Pic. 4. Distribution of equivalent von Mises stress values, MPa, of all traverse elements [developed by the authors].

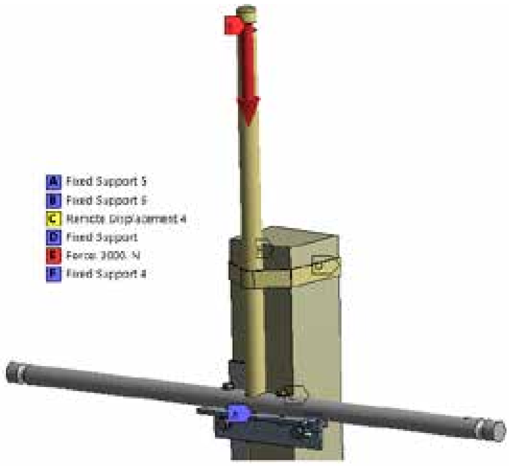
Determining the compliance of the main structural elements with strength conditions is made using the permissible stress method [or allowable stress design]:

$$[\sigma_{per}] \geq [\sigma_{EQUIV}] \quad (2)$$

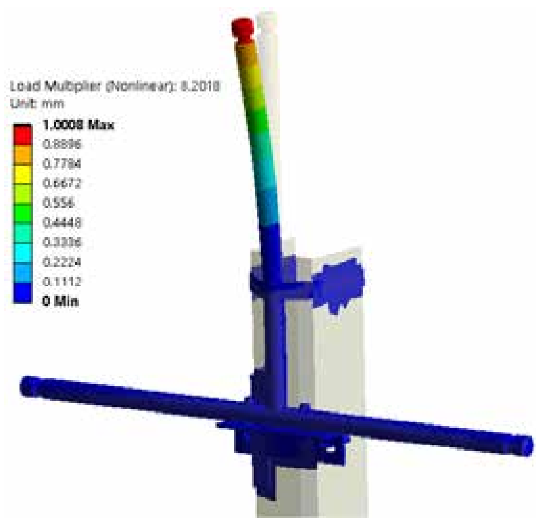
where $[\sigma_{EQUIV}]$ – maximum equivalent stress values arising in individual structural elements of the traverse.

The safety margin complies with GOST [Russian state standard] requirements. For all other structural elements, the safety factor is $\eta \geq 5$.

The next step is to determine the stability of the structure. The design model regarding the influence of a vertical axial compressive force of 3 kN (E) is shown in Pic. 5.



Pic. 5. Design model regarding the influence of compressive force on VTB in the vertical plane [developed by the authors]: A, B – (anchorage) free edges of CPM bolts; D, F – (anchorage) free edges of B; C – (limitation of movements in all directions) reverse side of the pole; E – (force) load applied in the vertical direction to VTB in the area of the wire fastening.



Pic. 6. Form of traverse buckling [developed by the authors].

Stability margin η_{stab} is determined according to the formula:

$\eta_{stab} = LM \cdot k,$ (3)

where LM – stability margin according to software calculation;

k –coefficient considering the imperfection of geometric shapes for compressed rods of variable cross-section k = 0,8.

The first form of buckling is shown in Pic. 6.

Minimum stability margin according to software calculation is LM = 8,2. η_{stab} = 8,2 • 0,8 = 6,56. The structure's stability margin ensures mechanical strength and meets the requirements [8; 9].

After the calculations have been carried out, the results obtained are compared with the results of calculations using the analytical method [8]. Comparative data are shown in Table 2.

Despite minor deviations from the classical method of calculating the strength of a composite traverse, a comparative analysis has shown that the estimated values and the convergence of the calculations obtained do not contradict the methods specified in [1, 2, 3].

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CONCLUSION

The work determined the mechanical strength of the TK-3-sh BOREL composite traverse, performed using the finite element method. According to the calculation results, the traverse meets the mechanical strength requirements.

A comparison of the analytical calculation method [8] and FEM calculation showed that the calculation error is no more than 15 %, which confirms the acceptability of the assumed features of the materials and assumptions in the calculations.

These techniques can be used in the design of traverses made of polymer composite materials. The materials of this work can be used in engineering calculations, as well as in the educational process when teaching students in specialties and areas of training: Electric power and electrical engineering (by industries); Electric power and electrical engineering; Train traffic supporting systems.

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Article received 20.07.2023, approved 22.11.2023, accepted 27.11.2023.