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## SIMULATION OF CURRENT DISTRIBUTION THROUGH ELEMENTS OF THE OVERHEAD CONTACT LINE

Symulacja rozpływu prądu przez elementy sieci jezdnej

**Abstract:** The compilation of unfavourable weather conditions, such as negative temperature and high humidity, leads to the formation of an ice layer and deposits on the elements of the overhead contact line, which leads to its degradation and prevents the supply of electricity to the traction vehicle. The traction line is located on a very large area and it is extremely difficult to effectively remove the remaining layers of ice. During planning the anti-icing measures it's very important to know the current distribution in wires. The authors of the article analysed the catenaries operated in Poland and in EU in terms of the current distributions in contact and catenary wires in through spans. The approach presented in this paper allows to take into account the wear of the contact wires during calculations of the current distributions.

Keywords: traction network, de-icing, current distribution, simulation

Streszczenie: Szereg niekorzystnych warunków atmosferycznych, takich jak ujemna temperatura i wysoka wilgotność, powoduje powstanie warstwy lodu i osadów na elementach sieci trakcyjnej, co prowadzi do jej degradacji i uniemożliwia dostarczanie energii elektrycznej do pojazdu trakcyjnego. Sieci trakcyjne znajdują się na rozległych obszarach i niezwykle trudno jest skutecznie usunąć warstwę lodu. Podczas planowania czynności mających na celu odlodzenie sieci jezdnych bardzo ważna jest znajomość rozpływu prądu w przewodach. Autorzy artykułu przeanalizowali sieci trakcyjne eksploatowane w Polsce i w UE pod kątem rozpływu prądów w przewodach jezdnych i linach nośnych w całym przęśle naprężenia. Przedstawione w niniejszej pracy podejście pozwala na uwzględnienie zużycia przewodów jezdnych podczas obliczeń rozpływu prądów Słowa kluczowe: sieć trakcyjna, odladzanie, rozpływ prądu, symulacja

### 1. Introduction

The problem of the occurrence of icing affects the proper functioning of all railway infrastructure managers with a traction network, including the largest manager in the country, i.e. PKP PLK S.A. It is therefore crucial to eliminate the impact of adverse weather conditions. The solution to the problem is to create an innovative power supply system for the overhead contact line elements, which will act as a current generator with appropriate parameters in order to increase the temperature of the contact wires, which in turn will prevent the formation of icing and frost for specific external conditions. An important stage in the creation of such a system is the simulation of current distribution in overhead contact lines, taking into account the wear of contact wires. There are various models of current distribution in contact networks [1]: a model of natural current distribution, linear analytical models, model with an infinite number of droppers, a model with a direct application of Kirchhoff's circuit laws in matrix form, and a finite element model [2]. In the existing publications, the wear of contact wires was not taken into account for the calculations of current fluxes [1-3]. This is a very important operating factor that affects the current flow. The work [4] discusses a model of the overhead contact line, the parameters of which were calculated on the basis of measurements in the laboratory of the Railway Institute. The article analyses all types of catenary operated on railway lines, in Poland and in Europe in terms of the number of contact wires and the number of catenary cables and stitch wires [5-8]. The distribution of current in contact lines was analysed in through spans, taking into account the wear of the contact wire.

# 2. Overhead contact line model for current distribution simulation

The analysis of current distribution in the overhead contact line was made on the basis of the overhead contact line model. In the proposed model, the elements of the overhead contact line are electrically connected to each other, constituting a system in which the contact wires and the catenary wire are the main carriers of electricity. The contact wires and the catenary wires work in parallel and are connected transversely through droppers, braces, suspension elements (cantilever, steady arms) and other electrical and mechanical connections made of conductive materials.

The simulation model of current distribution in the overhead contact line should take into account all these elements and connections. The input data for the construction of catenary models were catalogue data [5-8,15,16]. Network nodes are all points where at least two elements that make up a model are connected. Since the overhead contact line system operating in the DC system is considered, only resistive elements are present in the model. The fragment of the model of the span of contact line (screenshot of the "EasyEDA" simulation software window [9]) is shown in fig. 1.





Fig. 1. Model of the contact line span in EasyEDA programme

The resistances of the model elements were calculated as follows: the suspension elements (Rs) and braces (Rr) were determined on the basis of measurements. All measurements were made on three samples for four current values, and the average value of all measurements was adopted as the final measurement result [4].

The resistances of the catenary wire sections (RL), the stitch wire "Y" (RLy) and the contact wires (Rpj) were calculated as the product of the resistance of 1 m of the wire and the length of the wire between the nodes. In order to simplify the calculations in the model, the average values of the droppers' length were adopted for the calculation of their resistance Rw. Electrical connection resistance (Re) was determined in a similar way. All calculations were made assuming the unit values of resistance of wires as in Table 1.

#### Table 1

Type of wi	Resistivity,		
Symbol	Name or function	22/111	
DjpS150	Contact wire with a cross-section of 150 mm <sup>2</sup>	0.1167	
L10	Dropper wire with a cross-section of 10 mm <sup>2</sup>	1.77	
L35	Stitch wire "Y" with a cross-section of 35 mm <sup>2</sup>	0.5159	
L120	Catenary wire with a cross-section of 120 mm <sup>2</sup>	1.540	
L150	Catenary wire with a cross-section of 150 mm <sup>2</sup>	1.183	
L185	Wire for electrical connections with a cross-section of 185 mm <sup>2</sup>	1.015	
Djp100	Contact wire with a cross-section of 100 mm <sup>2</sup>	0.183	

#### Unit resistivity values [10-14]

## 3. Calculated method

All calculations were carried out in the EasyEDA simulation software [9] based on the model of through spans. For pass-through spans was carried out an analysis of the impact of contact wire wear on the nature of current distribution in the contact line (for values of wearing 0, 5, 10, 15 and 20%). The analysis of current distribution for the tension spans was carried out for two types of the catenary lines 2C120-2C-3 and YC150-2CS150 (contact wire wearing 0%).

## 4. Results of current distribution analysis

Contact lines on railway network in Poland can be divided in terms of construction into:

- with one contact wire, e.g. C95-C,
- with two contact wires, e.g. YC120-2C,
- with one supporting rope, e.g. C95-C,
- with two supporting ropes, e.g. 2C120-2C-3,
- with stitch wire Y and without Y.

The tension of one contact wire varies between 637 daN and 1483 daN. For catenary wires, these forces are be between 953 daN and 2012 daN. In addition, the stitch wire of the 2C120-2C-1 contact line is tensioned with a force of 500 daN. The conducted analyses, field and laboratory tests of the overhead contact line show that:

• 28 types of contact lines were created at the PKP,

• currently, 9 types of catenary are used in new overhead contact line projects; these are contact line with numbers 3 (C120-2C), 4 (C95-2C), 10 (C95-C), 26 (YwsC120-2C), 30 (YwsC120-2C-M), 32 (2C120-2C-3), 35 (2C120-2C-4), 36 (YC150-2CS150), 37 (YC150-2CS150), according to the Catalog [8].

Table 4 and Fig. 2 - present the results of the analysis of current distribution in the analyzed traction line in spans.

The distribution of currents in the tension span for contact lines 2C120-2C3 and YC150-2CS150 for analyzed contact lines is presented in Tables 2-4.

#### Table 2

					Total value
	Current share	Current share	Current share	Mean current	of current
Contact wire	in catenary	in the first	in the second	share in	share in
wear,%	wire	contact wire,	contact wire,	contact wire,	contact
	I <sub>LN</sub> , %	I Djp 1,%	I Djp 2,%	I Djp sr, %	wires,
					I Djp sum, %
0	17.7	15.4	15.7	15-55	31.1

Current distribution in the overhead contact line 2C120-2C-3 tension span



Fig. 2. Current in contact wire Djp for analyzed contact lines depending of wearing

#### Table 3

#### Current distribution in the overhead contact line YC150-2CS150 tension span

					Total value
	Current share	Current share	Current share	Mean current	of current
Contact wire	in catenary	in the first	in the second	share in	share in
wear, %	wire	contact wire,	contact wire,	contact wire,	contact
	ILN, %	I Djp 1,%	I Djp 2,%	I <sub>Djp sr</sub> , %	wires,
					I Djp sum, %
0	16.6	16.6	16.7	16.65	33

#### Table 4

Contact line         Contact wire wear, %         Resistivity of contact line, Ω/2km         Mare in contact wire, wear, %         Mare in contact wire, wire line, ontact wire, Ω/2km         Mare in contact wire, wire line, share in contact wire, Ω/2km         Ibps s. %         Ibps s. %         Ibps s. %         Ibps s. %           2C120-2C-3         0         0.0418         46.051         27.847         55.694           2C120-2C-3         10         0.04378         46.297         26.52         53.04           2D         0.046         48.401         25.055         50.11           2D         0.046         48.401         25.055         50.11           2D         0.0462         36.677         31.6165         63.233           2D         0.04124         35.984         32.008         64.016           15         0.0428         46.439         26.781         53.562           2C120-2C-4         10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.04486         49.311         25.345         50.69           15         0.0478         43.32         26.337         52.674           16         <	Type of Overhead			Current		
Contact line, wear, %         overhead Ω/km         Catenary wire Lix, %         Share in contact wire, Lix, %         Share in contact wire, Lix, %         Share in contact wire, Lix, %         Contact line, contact wire, Lix, %           2         0         0.0418         46.051         27.847         55.694           2         0.04486         47.653         26.0775         52.155           20         0.044         35.241         32.6845         65.369           5         0.0398         35.272         32.364         64.728           7         0         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         47.326         26.781         35.562           20         0.0448         48.28         25.86         51.72           20         0.0446         48.28         25.86         51.72           20         0.04613	Contact line	Contact	Resistivity of	share in	Mean current	Total value of
Numar, % wear, %         contact line, Ω/km         contact wire, lip x, %           2010.04428         46.073         26.075         50.11         63.323           0         0.04124         35.984         32.084         64.728           10         0.0413         37.612         31.194         62.388           0         0.0418         45.608         27.196         54.392           2010         0.0443         47.326         26.637         52.674           15         0.04486         48.28         25.86         51.72           202         0.0446         48.28         25.345         59.791           15         0.0	Contact mile	wire	overhead	catenary	share in	current share in
Norm         Ω/km         ILK, %         I bps w, %         I bps w, %           2         0         0.0418         46.051         27.847         55.694           2         10         0.04378         46.297         26.52         53.04           15         0.04436         47.653         26.0775         52.155           20         0.046         48.401         25.055         50.11           0         0.0385         34.631         32.6845         65.369           5         0.0398         35.272         32.364         64.016           15         0.0426         35.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           20         0.0443         37.612         31.194         62.383           20         0.0443         47.326         26.377         52.674           15         0.0428         46.439         26.781         53.552           201         0.0446         49.2311         25.345         50.69           10         0.05614         38.293         30.709         61.418           5         0.057986         39.377         30.3115		wear. %	contact line,	wire	contact wire,	contact wires,
0         0.0418         46.051         27.847         55.694           2C120-2C-3         5         0.0428         46.478         27.588         55.176           10         0.04378         46.297         26.52         53.04           15         0.04486         47.653         26.0775         52.155           20         0.046         48.401         25.055         50.11           0         0.0385         34.631         32.6845         65.369           5         0.0398         35.272         32.364         64.728           10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           0         0.0418         45.608         27.196         54.392           20         0.04486         48.28         25.86         51.72           20         0.0446         49.311         25.345         50.69           15         0.0514         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623     <		wear, 70	Ω/km	ILN, %	I Djp sr, %	I Djp sum, %
5         0.0428         46.478         27.588         55.176           10         0.04378         46.297         26.52         53.04           10         0.04386         47.653         26.60775         52.155           20         0.046         48.401         25.055         50.11           0         0.0385         34.631         32.6845         65.369           5         0.0398         35.272         32.364         64.728           10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           0         0.0418         45.608         27.196         54.392           5         0.0428         46.439         26.781         53.562           2010         0.04486         48.28         25.86         51.72           20         0.04486         48.28         25.86         51.72           20         0.0464         49.311         25.345         50.69           15         0.05794         40.21         29.8955         59.791           15		0	0.0418	46.051	27.847	55.694
2C120-2C-3         10         0.04378         46.297         26.52         53.04           15         0.04486         47.653         20.0775         52.155           20         0.046         48.401         25.055         50.11           0         0.0385         34.631         32.0845         65.369           5         0.0398         35.272         32.364         64.728           10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           20         0.0418         45.608         27.196         54.392           210         0.0428         46.439         26.781         53.562           201         0.0446         48.28         25.86         51.72           20         0.044         38.573         30.709         61.418           5         0.057986         39.377         30.3115         60.623           YwsC120-2C         10         0.054934         41.129         29.4355         58.71           20         0.0443         36.673         31.815<		5	0.0428	46.478	27.588	55.176
15         0.04486         47.653         26.0775         52.155           20         0.046         48.401         25.055         50.11           20         0.0385         34.631         32.6845         65.369           5         0.0398         35.272         32.364         64.728           10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           0         0.0418         45.608         27.196         54.392           5         0.0428         46.439         26.781         53.562           2010         0.0448         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           15         0.0486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           15         0.05794         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20	2C120-2C-3	10	0.04378	46.297	26.52	53.04
20         0.046         48.401         25.055         50.11           0         0.0385         34.631         32.6845         65.369           5         0.0398         35.272         32.364         64.728           10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           0         0.0418         45.608         27.196         53.562           2012-2C-4         10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.0461         49.311         25.345         50.69           10         0.057986         39.377         30.3115         60.623           115         0.061784         41.129         29.4355         58.871           200         0.064034         42.132         28.934         57.868           15         0.042         35.673         32.1815         64.363           15         0.042         35.673         32.1815         64.363 </td <td></td> <td>15</td> <td>0.04486</td> <td>47.653</td> <td>26.0775</td> <td>52.155</td>		15	0.04486	47.653	26.0775	52.155
0         0.0385         34.631         32.6845         65.369           YC150-2CS150         5         0.0398         35.272         32.364         64.016           10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           20         0.0418         45.608         27.196         54.392           20         0.0428         46.439         26.781         53.562           10         0.04378         47.26         26.337         52.674           15         0.0464         49.311         25.345         50.69           10         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           YwsC120-2C         10         0.0601784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           YC120-2C150         10         0.0405         34.972         32.1815         64.363           15         0.042		20	0.046	48.401	25.055	50.11
5         0.0398         35.272         32.364         64.728           YC150-2CS150         10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.94         62.388           20         0.0428         46.439         26.781         53.562           10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           15         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           YC120-2C150         10         0.0425         35.673         32.		0	0.0385	34.631	32.6845	65.369
YC150-2CS150         10         0.04124         35.984         32.008         64.016           15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           20         0.0418         45.608         27.196         54.392           5         0.0428         46.439         26.781         53.562           2010         0.046         49.311         25.345         50.69           0         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           YwsC120-2C         10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           YC120-2C150         10         0.04361         36.37         31.815         63.63           15         0.0441		5	0.0398	35.272	32.364	64.728
15         0.0426         36.767         31.6165         63.233           20         0.0443         37.612         31.194         62.388           0         0.0418         45.608         27.196         54.392           5         0.0428         46.439         26.781         53.562           10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           0         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.04055         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           15         0.0451         37.155         31.427         62.854	YC150-2CS150	10	0.04124	35.984	32.008	64.016
20         0.0443         37.612         31.194         62.388           0         0.0418         45.608         27.196         54.392           5         0.0428         46.439         26.781         53.562           10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           20         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966		15	0.0426	36.767	31.6165	63.233
0         0.0418         45.608         27.196         54.392           2C120-2C-4         5         0.0428         46.439         26.781         53.562           10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           0         0.05514         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.06403         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0421         32.469         33.7655         67.531           20         0.0471         38.034         30.983         61.966		20	0.0443	37.612	31.194	62.388
5         0.0428         46.439         26.781         53.562           2C120-2C-4         10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           0         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.04451         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966           5         0.0666         34.071         32.969         65.751		0	0.0418	45.608	27.196	54.392
2C120-2C-4         10         0.04378         47.326         26.337         52.674           15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           20         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0421         32.649         33.7655         67.531           20         0.047         38.034         30.983         61.966           6         0.0621         32.469         33.755         66.751           5         0.0692         34.918         32.509         65.018		5	0.0428	46.439	26.781	53.562
15         0.04486         48.28         25.86         51.72           20         0.046         49.311         25.345         50.69           20         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           15         0.0451         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966           15         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018	2C120-2C-4	10	0.04378	47.326	26.337	52.674
10         10/10         10/10         10/10         10/10           20         0.046         49.311         25.345         50.69           9         0.05614         38.593         30.709         61.418           5         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0421         32.469         33.7655         67.531           20         0.047         38.034         30.983         61.966           10         0.0666         34.071         32.509         65.731           20         0.072         35.767         32.117         64.234           20         0.072         35.767         32.117         64.234		15	0.04486	48.28	25.86	51.72
$ \begin{array}{c cccc} YwsC120-2C & 0.05614 & 38.593 & 30.709 & 61.418 \\ \hline 5 & 0.057986 & 39.377 & 30.3115 & 60.623 \\ \hline 10 & 0.059754 & 40.21 & 29.8955 & 59.791 \\ \hline 15 & 0.061784 & 41.129 & 29.4355 & 58.871 \\ \hline 20 & 0.064034 & 42.132 & 28.934 & 57.868 \\ \hline 0 & 0.0405 & 34.972 & 32.514 & 65.028 \\ \hline 5 & 0.042 & 35.673 & 32.1815 & 64.363 \\ \hline 15 & 0.0451 & 36.37 & 31.815 & 63.63 \\ \hline 15 & 0.0451 & 37.155 & 31.427 & 62.854 \\ \hline 20 & 0.047 & 38.034 & 30.983 & 61.966 \\ \hline 20 & 0.0644 & 33.25 & 33.3755 & 66.751 \\ \hline 5 & 0.0644 & 33.25 & 33.3755 & 66.751 \\ \hline 5 & 0.0644 & 33.25 & 33.3755 & 66.751 \\ \hline 10 & 0.0666 & 34.071 & 32.9645 & 65.929 \\ \hline 15 & 0.0692 & 34.918 & 32.509 & 65.018 \\ \hline 20 & 0.0574 & 35.604 & 32.1985 & 64.397 \\ \hline 5 & 0.0593 & 36.418 & 31.441 & 62.882 \\ \hline 10 & 0.0612 & 37.448 & 31.2765 & 62.553 \\ \hline 15 & 0.0633 & 38.241 & 30.88 & 61.76 \\ \hline 20 & 0.0567 & 39.268 & 30.366 & 60.732 \\ \hline 0 & 0.0941 & 48.962 & 51.038 & 51.038 \\ \hline 5 & 0.0992 & 50.883 & 49.117 & 49.117 \\ \hline 15 & 0.102 & 51.943 & 48.057 & 48.057 \\ \hline \end{array}$		20	0.046	49 311	25.345	50.69
Solution         Solution         Solution         Solution         Solution           YwsC120-2C         10         0.057986         39.377         30.3115         60.623           10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0421         32.673         32.1815         64.363           20         0.047         38.034         30.983         61.966           20         0.047         38.034         30.983         61.966           20         0.047         38.034         30.983         61.966           20         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           20         0.072         35.767         32.117		0	0.05614	38 593	30,709	61 418
YwsC120-2C         10         0.059754         40.21         29.8955         59.791           15         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0451         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966           15         0.0421         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882		5	0.057986	39.377	30.3115	60.623
10         0.061784         41.129         29.4355         58.871           20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0421         32.469         33.7655         67.531           20         0.047         38.034         30.983         61.966           20         0.044         33.25         33.3755         66.751           20         0.0644         33.25         33.3755         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           20         0.072         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           20         0.06567         39.268         30.366         60.732           15         0.0633         38.241         30.88         61.76	YwsC120-2C	10	0.059754	40.21	29.8955	59.791
20         0.064034         42.132         28.934         57.868           0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.0421         32.649         33.7655         67.531           20         0.047         38.034         30.983         61.966           20         0.047         38.034         30.983         61.966           20         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           20         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           20         0.0612         37.448         31.2765         62.553 <td< td=""><td></td><td>15</td><td>0.061784</td><td>41.129</td><td>29.4355</td><td>58.871</td></td<>		15	0.061784	41.129	29.4355	58.871
VC120-2C150         0         0.0405         34.972         32.514         65.028           5         0.042         35.673         32.1815         64.363           10         0.04361         36.37         31.815         63.63           15         0.047         38.034         30.983         61.966           20         0.047         38.034         30.983         61.966           0         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           20         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732 </td <td></td> <td>20</td> <td>0.064034</td> <td>42.132</td> <td>28.934</td> <td>57.868</td>		20	0.064034	42.132	28.934	57.868
5         0.042         35.673         32.1815         64.363           YC120-2C150         10         0.04361         36.37         31.815         63.63           15         0.0451         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966           0         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           20         0.072         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           15         0.09675         49.895         50.105         50.105		0	0.0405	34.972	32.514	65.028
YC120-2C150         10         0.04361         36.37         31.815         63.63           15         0.0451         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966           0         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.09941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105		5	0.042	35.673	32.1815	64.363
15         0.0451         37.155         31.427         62.854           20         0.047         38.034         30.983         61.966           20         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.09941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117	YC120-2C150	10	0.04361	36.37	31.815	63.63
20         0.047         38.034         30.983         61.966           0         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.09941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		15	0.0451	37.155	31.427	62.854
0         0.0621         32.469         33.7655         67.531           5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.09941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		20	0.047	38.034	30.983	61.966
5         0.0644         33.25         33.3755         66.751           10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.09941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		0	0.0621	32.469	33.7655	67.531
C95-2C         10         0.0666         34.071         32.9645         65.929           15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.09941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		5	0.0644	33.25	33.3755	66.751
15         0.0692         34.918         32.509         65.018           20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057	C95-2C	10	0.0666	34.071	32.9645	65.929
20         0.072         35.767         32.117         64.234           0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		15	0.0692	34.918	32.509	65.018
0         0.0574         35.604         32.1985         64.397           5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		20	0.072	35.767	32.117	64.234
5         0.0593         36.418         31.441         62.882           10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		0	0.0574	35.604	32.1985	64.397
C120-2C         10         0.0612         37.448         31.2765         62.553           15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		5	0.0593	36.418	31.441	62.882
15         0.0633         38.241         30.88         61.76           20         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057	C120-2C	10	0.0612	37.448	31,2765	62,553
10         0.0000         0.0000         0.0000         0.0000           20         0.06567         39.268         30.366         60.732           0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		15	0.0633	38.241	30.88	61.76
0         0.0941         48.962         51.038         51.038           5         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		20	0.06567	39.268	30.366	60.732
C95-C         0.09675         49.895         50.105         50.105           10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		0	0.0941	48.962	51.038	51.038
C95-C         10         0.0992         50.883         49.117         49.117           15         0.102         51.943         48.057         48.057		5	0.09675	49 895	50.105	50 105
10         0.092         50.005         49.117         49.117           15         0.102         51.943         48.057         48.057	C95-C	10	0.0992	50.883	49 117	49 117
13 0.102 51.745 40.057 40.057	0,5-0	15	0.102	51.943	48.057	48.057
		20	0.102	53.075	46.025	46.025
20 $0.103$ $55.075$ $40.525$ $40.525$ $VnC95-2C$ 0         0.061         37.31         31.345         62.60	VnC95-2C	0	0.061	37.31	31 345	62.69

#### Current distribution in the analysed overhead contact lines

	5	0.063	38.124	30.9385	61.877
	10	0.065	38.983	30.5085	61.017
	15	0.0674	39.926	30.037	60.074
	20	0.07	40.948	29.5255	59.051
	0	0.05614	35.805	32.0975	64.195
	5	0.057986	36.633	31.6835	63.367
YpC120-2C	10	0.059754	37.446	31.2775	62.555
_	15	0.061784	38.373	30.8135	61.627
	20	0.064034	39.381	30.3095	60.619
	0	0.1095	64.111	35.889	35.889
	5	0.113	64.856	35.144	35.144
SKB-70C	10	0.1163	65.641	34.359	34.359
	15	0.12	66.48	33.519	33.519
	20	0.1243	67.38	32.62	32.62
	0	0.05614	38.547	30.7265	61.453
	5	0.057986	39.354	30.323	60.646
YwsC120-2C-M	10	0.059754	40.2	29.9005	59.801
	15	0.061784	41.132	29.434	58.868
	20	0.064034	42.148	28.926	57.852
	0	0.05614	35.6	32.2	64.4
	5	0.057986	36.403	31.7985	63.597
YC120-2C	10	0.059754	37.005	31.4975	62.995
	15	0.061784	38.187	30.9065	61.813
	20	0.064034	39.201	30.3995	60.799
	0	0.061	38.956	30.522	61.044
	5	0.063	39.975	30.1025	60.205
YC95-2C	10	0.065	40.678	29.671	59.342
	15	0.0674	41.646	29.1775	58.355
	20	0.07	42.693	28.6535	57.307

## 5. Conclusion

1. On the basis of the conducted analysis of current distribution in 14 traction lines in spans, the following was found:

- the distribution of currents is influenced by the design of the overhead contact line and the wear of contact wires. Wear of contact wires reduces the percentage of current in the contact wire. For the analyzed overhead contact lines with two contact wires, the average percentage of current in one contact wire varied from 35.9% to 25.1% of the overhead contact line current depending on the value of contact wire wearing,

- for the C95-C overhead contact line, the average percentage of current in the contact wire varied from 51% to 46.9%.

In the other analyzed traction lines listed in Table 1, the nature of current distribution in the spans is the same.

2. The current distribution in the spans of the contact lines 2C120-2C3 and YC150-2CS150 differs significantly from the current distribution in the spans.

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## 6. References

- 1. Batrashov A.: Comparison of current distribution models in direct current catenaries, IzvestiyaTranssib, no. 1, p.4(32), pp. 54–66, 2017.
- 2. Paranin A.V.: Finite-Element Model Based Distribution Calculations of Current and Temperature within a DC Overhead. Bulletin VNIIZhT. no. 6, pp. 33–38, 2015.
- 3. Kiessling F., Puschmann R., Schmieder A., Schneider E.: Contact Lines for Electric Railways: Planning, Design, Implementation, Maintenance, 3rd Edition. Wiley, 2018.
- Skrzyniarz M., Kruczek W., Mike K., Stypułkowski P.: Development of a model of current distribution in the overhead contact lines for an innovative de-icing system. Problemy Kolejnictwa, vol. 66, iss. 195, 2022.
- 5. PN-EN 50149:2012. Railway applications Stationary equipment Profiled contact wires made of copper and its alloys.
- 6. Catalogue of Railway Electrification Elements. overhead contact line CBPiBBK "Kolprojekt" Sp. z o.o. Warsaw 1992.
- 7. Overhead contact line catalogue YC150-2CS150 overhead contact line with variant YV120-2CS150. CBPiBBK "Kolprojekt" Sp. z o.o. Warsaw 2010.
- 8. KOLPROJEKT, "Overhead contact line catalogue. overhead contact line Pipe suspensions.' 2004.
- 9. An Easier and Powerful Online PCB Design Tool https://easyeda.com/ [accessed 06.06.2022]
- 10. Normative document 01-3/ET/2008 Iet 113 profiled contact wires. 2008.
- 11. PKPPLK, "NORMATIVE DOCUMENT 01-4/ET/2008 Wires (bare multicore conductors) Iet-114." 2008.
- 12. Fang Y., Zhang Y. (eds.): China's High-Speed Rail Technology. An International Perspective. Springer, 2018.
- Kaniewski M., Kuznetsov V., Hubskyi P., Sychenko V., Antonov A.: Modeling the Quality of Current Collection Under the Conditions of a Growing Speed of Rolling Stock. Transport Means 2020 - Proceedings of the 24th International Scientific Conference. Part I, 260–264, 2020.
- 14. Keenor G.: Overhead Line Electrification For Railways. 5th ed., 2018.
- Product catalog. Contact line equipment for mass transit and main-line railways. Siemens. CL V 1.0. Retrieved from https://assets.new.siemens.com/siemens/assets/api/uuid:a406c8a0-064d-4c4f-8065-0b6edd53ec48/siemens-contact-line-material-cat-en.pdf

16. UIC. (2000). UIC 799-1 Characteristics of direct-current overhead contact systems for lines worked at speeds of over 160 km/h and up to 250 km/h.