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Influence of Overhead Line Equipment Irregularities on Pantograph-Catenary Interaction

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Abstract

Achieving good contact quality between the pantograph and overhead line equipment (OLE) is fundamental to ensure reliable electric railway operation. Contact wire irregularities may affect the pantograph-OLE interaction and stability of current collection. Therefore, the maintenance of the OLE and the study of the impact of such geometric deviations is a field of interest. In the present paper, the influence of OLE irregularities, in both its vertical and lateral directions, on pantograph-catenary interaction is studied. OLE finite element models are built, from a nominal baseline scenario to increasing levels of irregularities, and are subsequently used to perform dynamic analyses and assessment of contact forces. The results demonstrate that, at conventional speeds (up to 100 mph) and in single pantograph operation, the presence of irregularities within the maintenance thresholds does not adversely impact contact quality. Increasing the irregularities by 100% leads to a dynamic performance still within the applicable thresholds, which may indicate that the current maintenance limits are overly conservative.

Keywords: pantograph-catenary interaction, catenary irregularities, current collection performance, contact forces, maintenance limits, 3D finite element model.

1 Introduction

The efficient operation of an electrified railway line relies on the effective performance of both the pantograph and the overhead line equipment (OLE) to ensure high-quality current collection. Variations in contact force, resulting from the dynamic interaction between the contacting surfaces, can adversely affect current collection quality. Excessive contact force can lead to significant uplift and increased mechanical wear of the contact wire and/or contact strips. On the other hand, if the contact force is too low, there is a higher likelihood of contact loss, which can cause arcing and lead to increased electrical wear on both the contact wire and the contact strip. Catenary geometry deviations can become very important for the pantograph-OLE interaction, especially as it becomes more relevant with continued operation and added wear. Effective maintenance is therefore mandatory to ensure efficient and reliable current collection. Since maintenance requires knowledge regarding the state of the OLE at a given time, remote condition monitoring is an active field of research.

To study the above mentioned problems, reliable numerical tools should be used. In this work, *PantoCat* [1] is employed to create detailed 3D models with several irregularity profiles and analyse their effects on pantograph-OLE interaction. Zhang et al [2] and Collina et al [3] studied the influence of vertical contact wire irregularities by means of numerical simulation based on the finite element formulation. Qin et al [4] performed a similar study, also focused on vertical irregularities, but with the contact force determined via neural networks trained on experimental data. Song et al [5] analysed the spectral distribution of vertical irregularities from experimental measurements, and used the resulting PSD to generate random irregularity profiles and perform a stochastic analysis of contact force statistics. Further work was developed on the influence of vertical irregularities on high-speed operations [6] and, in a similar manner, the effect of contact wire presag under different wire tensions and train speeds [7].

2 Pantograph and OLE Modelling

The OLE design selected for this work is the Network Rail (NR) UK Master Series 100 (UKMS100). The pantograph model selected is the Brecknell Willis HSX. The following details the modelling of each subsystem.

The OLE design selected is the UKMS100. The models are built according to the finite element (FE) formulation and using data from the relevant NR manuals [8]. A summary of the parameters required to describe the beam elements is presented in Table 1.

Parameter	Unit	Contact Wire	Messenger Wire	Droppers	Steady Arm
Cross Section	m^2	1.07E-04	6.58E-05	1.00E-05	3.11E-04
Linear Mass	kg/m	9.52E-01	5.96E-01	9.30E-02	1.36E+00
Young Modulus	Pa	1.15E+11	1.13E+11	1.13E+11	7.10E+10
Tension	N	1.10E+04	1.10E+04	n.a.	n.a.

Table 1: Material properties for UKMS100 components.

Nominal contact wire height is 4.700 m, and nominal encumbrance is 1.3 m. Nominal straight line stagger is 0.230 m for both the contact and messenger wires. A standard span length of 60 m is selected, and the design presag is 1:1000.

Two wire runs are built, the first with 800 m and the second with 1500 m, both with overlap zones. The irregularities are applied only on the second wire run, while the dynamic analysis start on the first wire run. This is to ensure that transient effects created by the first contact of the pantograph on the OLE do not impact the dynamic results within the area of interest of the analysis (10 spans, from 1100 m to 1700 m).

The FE mesh of a nominal OLE without irregularities is depicted from the side and from the top in Figure 1 and Figure 2 respectively. The contact wire (CW) is depicted in blue, the messenger wire (MW) in green, the steady arms in red, and the droppers in grey. From the side view it is possible to see the presag of the contact wire in each span, as well as the overlaps. The top view clearly depicts the stagger of both wires, as well as the increase stagger at the terminations of the wire runs.

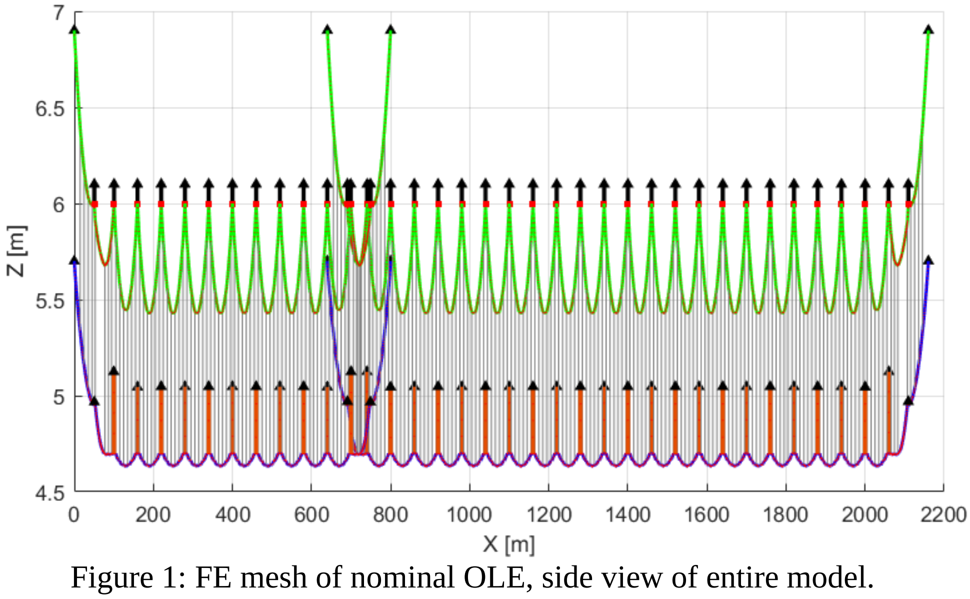


Figure 1: FE mesh of nominal OLE, side view of entire model.

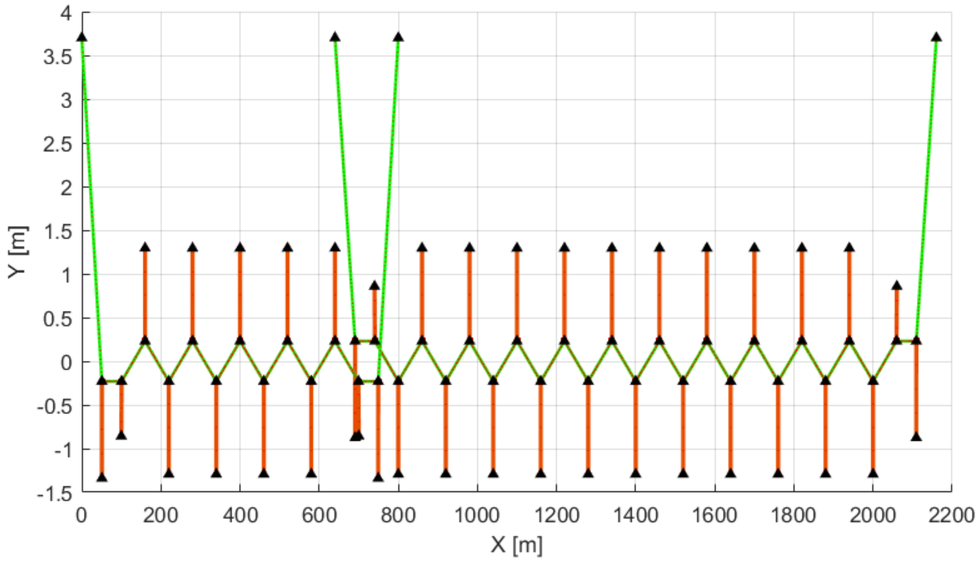


Figure 2: FE mesh of nominal OLE, top view of entire model.

Network Rail establishes geometric tolerances for both installation and maintenance in the relevant manuals [9], [10]. The tolerances selected for this work are described in Table 2.

Description	Tolerance
Dropper length	±5mm
CW height at supports (open route)	±15mm
CW and MW stagger	±25mm
MW to CW stagger alignment	±150mm

Table 2: UKMS100 geometric tolerances.

A FE model is built for each OLE with a different irregularity profile applied, as well as one model with no irregularities (to serve as a baseline) and one with all irregularities combined. The list of OLE models built, with their respective IDs and irregularities applied, is described below:

IRR0 –without irregularities;
IRR1 – with vertical irregularities on the CW (height at supports);
IRR2 – with vertical irregularities on the CW (presag);
IRR3 – with lateral irregularities on the CW and MW (stagger at supports);
IRR4 – with irregularities on the CW and MW stagger alignment;
IRR5 – with all irregularities combined;
IRR6 – with all irregularities at +100% of their magnitude.

The FE mesh of the OLE models IRR0 and IRR6 is presented in Figure 3 and Figure 4, focusing on the area of interest and highlighting the irregularities applied to each model. Please note the differences in scaling between the axis of each figure.

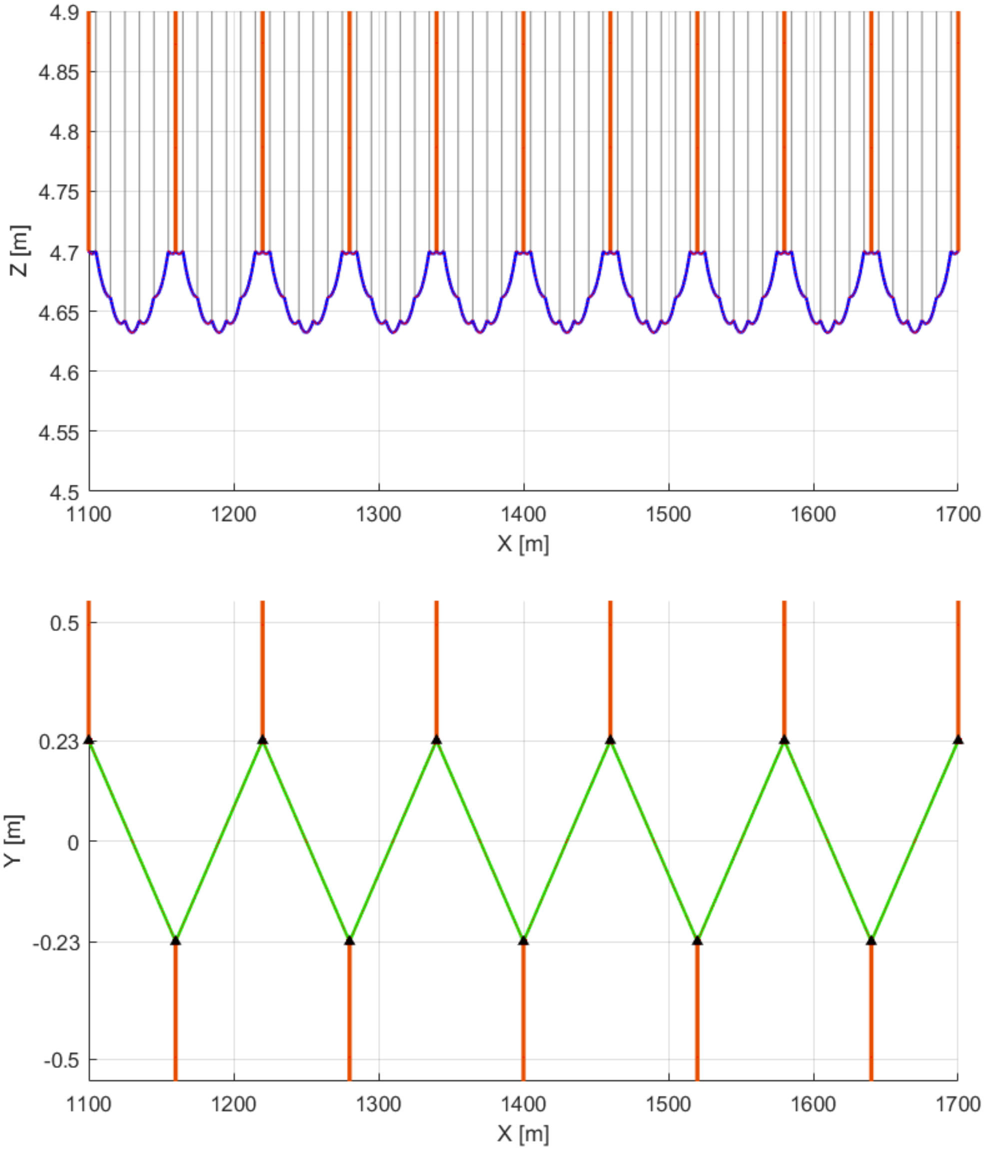


Figure 3: FE mesh of IRR0, side and top views

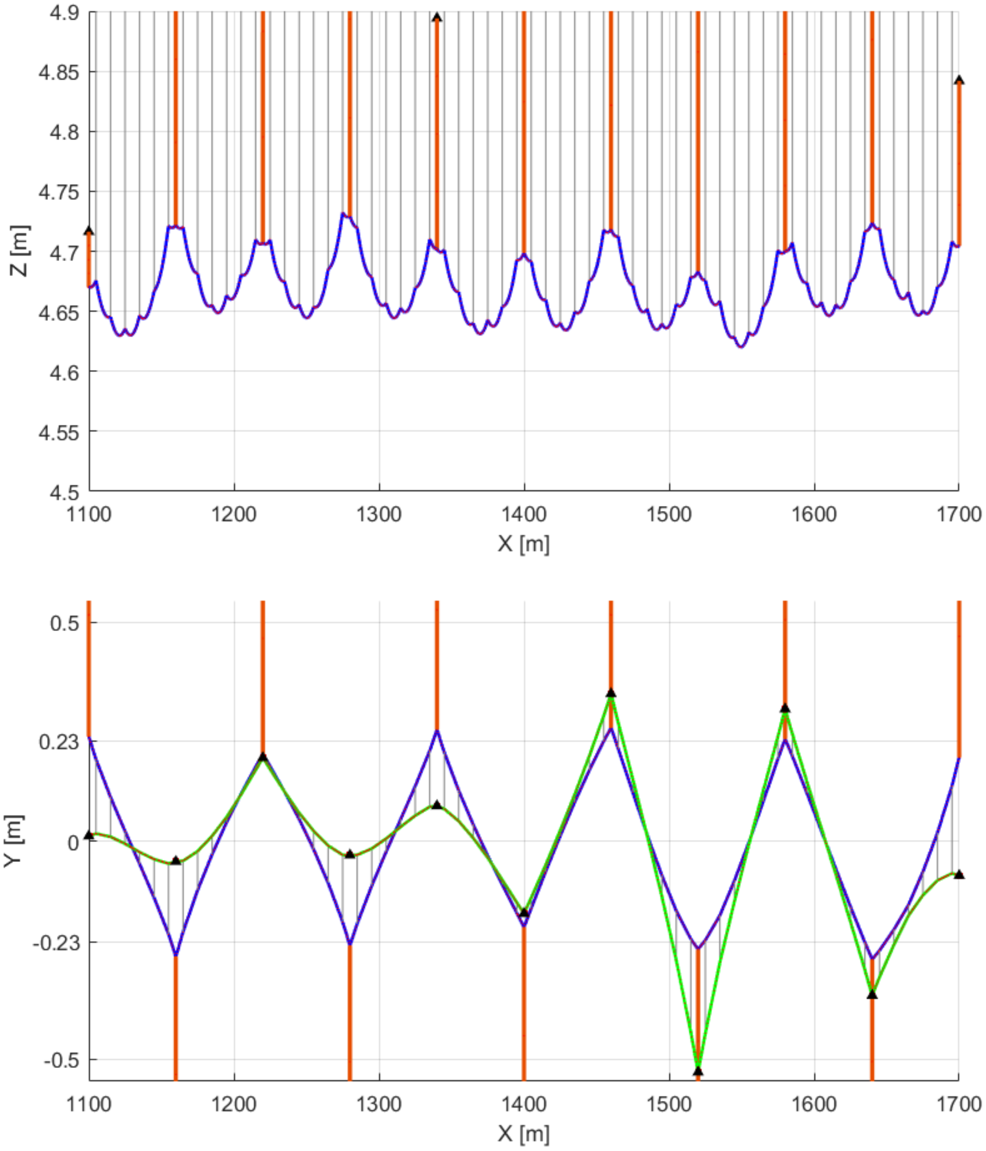
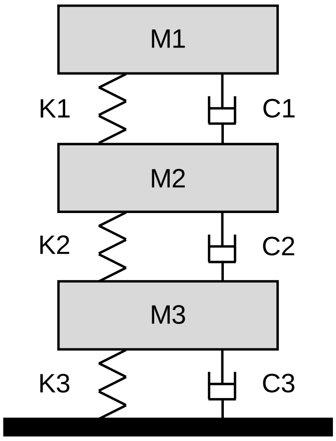


Figure 4: FE mesh of IRR6, side and top views

The Brecknell Willis HSX pantograph is modelled as a linear three-stage lumped-mass system, with springs and dampers. The parameters of the model are determined experimentally by DB Munich [11], and are presented in Figure 5.



ID	Value	Units
M1	5.30	kg
M2	7.50	
M3	3.53	
K1	6300	N/m
K2	5000	
K3	0	
C1	70	Ns/m
C2	0	
C3	32.6	

Figure 5: Lumped-mass model of the HSX pantograph.

3 Results

The dynamic analyses are performed on the six OLE models described, operating with a single pantograph at 100 mph and 90 N of static uplift force. The aerodynamic uplift applied is as described in [12].

The statistics of the contact force, filtered between 0 and 20 Hz, are presented in Table 3. The dynamic performance is similar for all scenarios with variations of less than 0.5 N in standard deviation between the OLE with and without irregularities. This is expected, as the irregularities included are within the maintenance tolerance limits and therefore should not adversely impact the contact quality. Likewise, adding all irregularities in the same model, scenario IRR5, does not lead to a noticeable deterioration of dynamic performance.

For scenario IRR6, with irregularities with twice the magnitude, the maximum and minimum contact forces present a bigger variation, which in turn leads to a force amplitude 20 N higher than on the baseline scenario IRR0. Standard deviation also increases, while the SD/mean force ratio remains under the threshold of 0.3 commonly used for contact quality assessment [12].

OLE Model	Contact force [N] [0 - 20 Hz]							
	Max	Min	Amp	Mean	SD	SD/Mean	St Max	St Min
0	147.4	67.4	80.0	102.2	16.1	0.158	150.5	53.8
1	148.2	67.9	80.3	102.1	16.1	0.158	150.5	53.7
2	149.2	64.6	84.7	102.2	16.0	0.157	150.3	54.1
3	147.8	67.7	80.1	102.2	16.1	0.157	150.4	53.9
4	145.6	67.1	78.5	102.2	15.7	0.153	149.2	55.1
5	145.2	64.0	81.2	102.1	15.6	0.152	148.8	55.4
6	156.5	56.6	99.9	102.1	16.4	0.160	151.2	52.9

Table 3: Statistics of the contact force.

Further study is performed by analysing the contact force history of scenarios 0, 5 and 6, presented in Figure 6 to Figure 8. The addition of irregularities reduces the purely sinusoidal and uniform behaviour of the contact force, introducing deviations that are also present in real life measurements. Consequently, compared to scenario IRR0, the distribution of the contact forces of scenario IRR6 better resembles that of a normal distribution, as visible in the histograms in Figure 9 and Figure 10.

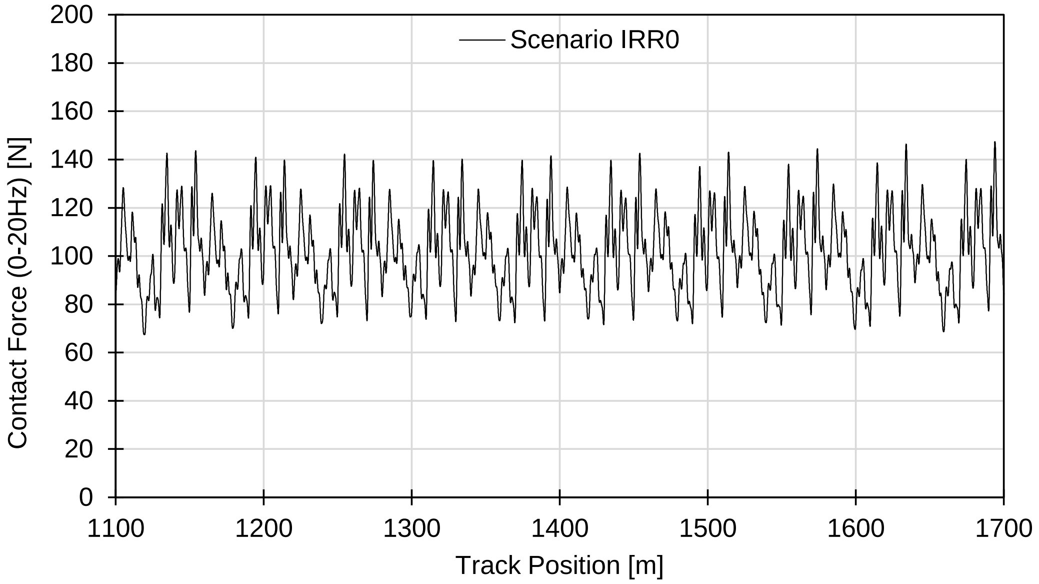


Figure 6: Contact force history of scenario IRR0.

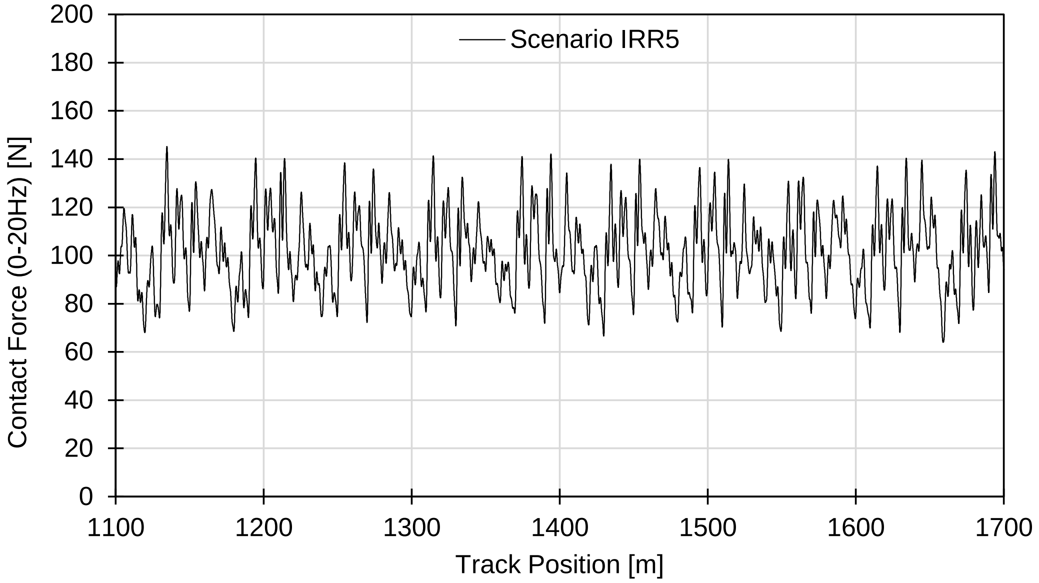


Figure 7: Contact force history of scenario IRR5.

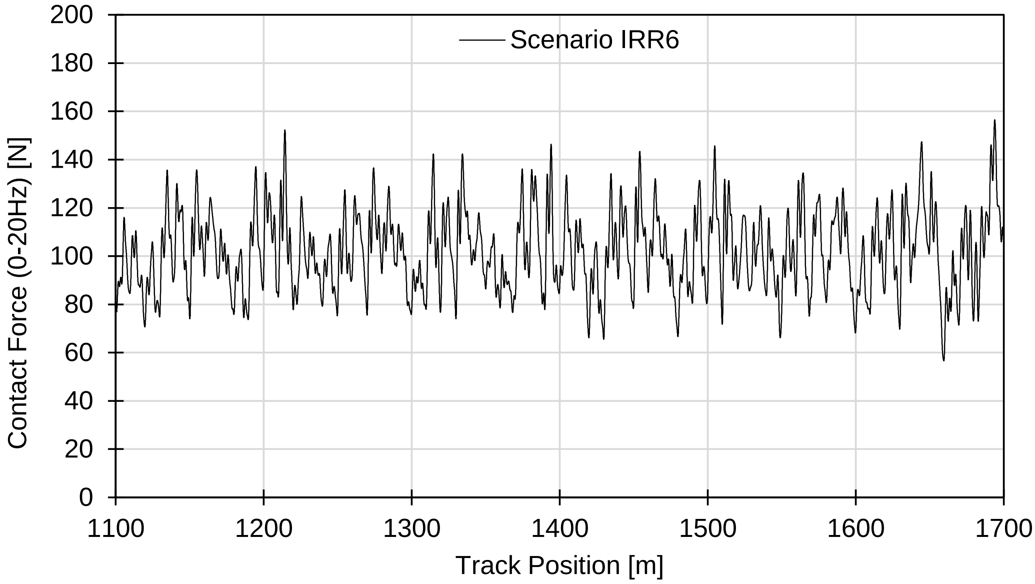


Figure 8: Contact force history of scenario IRR6.

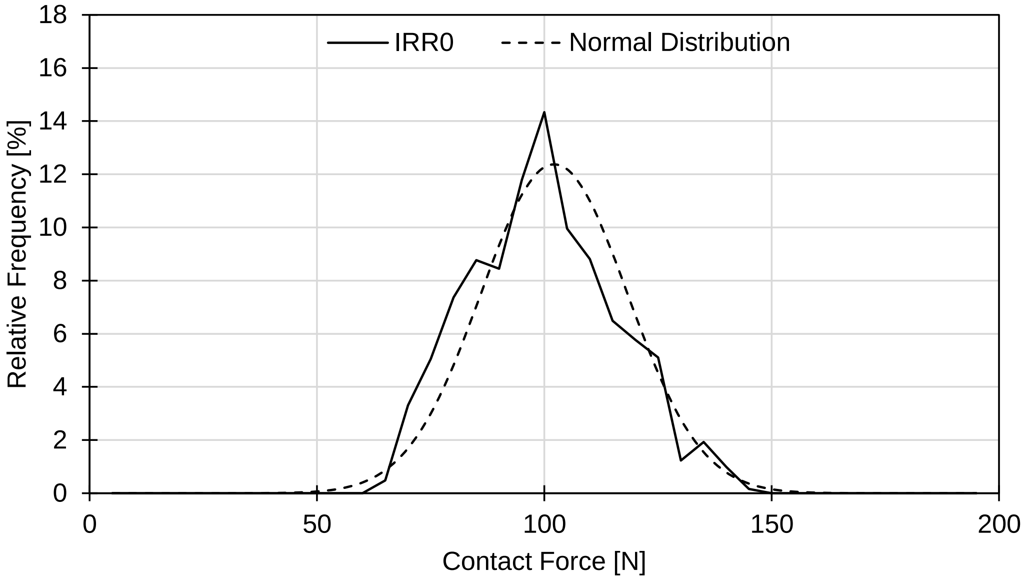


Figure 9: Contact force histogram of scenario IRR0.

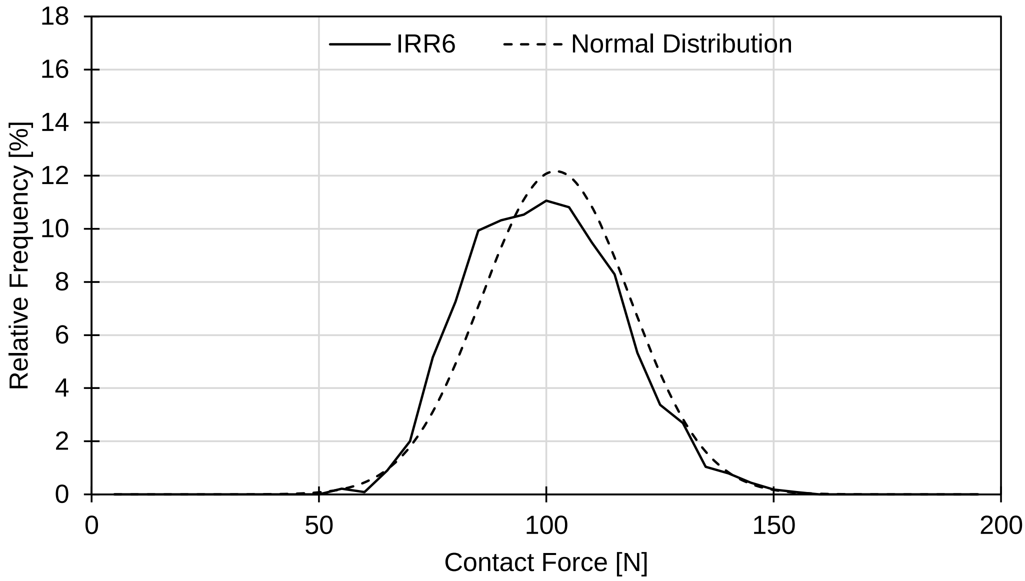


Figure 10: Contact force histogram of scenario IRR6.

4 Conclusions and Contributions

In this work, six UKMS100-based OLEs with vertical and lateral irregularities are modelled, and their performance in terms of contact quality is assessed. Dynamic analyses are performed with a HSX pantograph travelling at 100 mph. At this speed, the presence of irregularities of magnitude within the specified maintenance thresholds does not adversely impact the dynamic performance. Increasing the value of the irregularities by 100% leads to an increase of 20 N in force amplitude, while standard deviation only increases by 0.5 N compared to the baseline scenario without irregularities. This may indicate that the current maintenance limits are excessively conservative and that there may be some allowance for increasing their values.

Analysis of the contact force histories shows that the presence of irregularities increases the variability of the forces, which present a less sinusoidal and periodic behavior. This fact is further visible in the histograms of the contact forces, in which the force distribution better resembles that of a normal distribution.

Acknowledgements

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References

[1] J. Ambrósio, J. Pombo, P. Antunes, and M. Pereira, “PantoCat statement of method,” *Vehicle System Dynamics*, vol. 53, no. 3, pp. 314–328, Nov. 2015, doi: 10.1080/00423114.2014.969283.

[2] W. Zhang, G. Mei, and J. Zeng, “A study of pantograph/catenary system dynamics with influence of presag and irregularity of contact wire,” in

Vehicle System Dynamics, Swets en Zeitlinger B.V., 2002. doi: 10.1080/00423114.2002.11666265.

[3] A. Collina, F. Fossati, M. Papi, and F. Resta, "Impact of overhead line irregularity on current collection and diagnostics based on the measurement of pantograph dynamics," *Proc Inst Mech Eng F J Rail Rapid Transit*, vol. 221, no. 4, pp. 547–559, 2007, doi: 10.1243/09544097F02105.

[4] Y. Qin, Y. Zhang, X. Q. Cheng, L. M. Jia, and Z. Y. Xing, "An analysis method for correlation between catenary irregularities and pantograph-catenary contact force," *J Cent South Univ*, vol. 21, no. 8, pp. 3353–3360, 2014, doi: 10.1007/s11771-014-2309-5.

[5] Y. Song, Z. Liu, A. Ronnquist, P. Navik, and Z. Liu, "Contact Wire Irregularity Stochastics and Effect on High-Speed Railway Pantograph-Catenary Interactions," *IEEE Trans Instrum Meas*, vol. 69, no. 10, pp. 8196–8206, Oct. 2020, doi: 10.1109/TIM.2020.2987457.

[6] Y. Song, P. Antunes, J. Pombo, and Z. Liu, "A methodology to study high-speed pantograph-catenary interaction with realistic contact wire irregularities," *Mech Mach Theory*, vol. 152, Oct. 2020, doi: 10.1016/j.mechmachtheory.2020.103940.

[7] G. Mei and Y. Song, "Effect of Overhead Contact Line Pre-Sag on the Interaction Performance with a Pantograph in Electrified Railways," *Energies (Basel)*, vol. 15, no. 19, Oct. 2022, doi: 10.3390/en15196875.

[8] Network Rail, "UKMS System Description Manual Issue 2.2 (141667-FAF-MAN-EOH-000001)," 2022.

[9] Network Rail, "UKMS Installation Manual Issue 2.1 (141667-FAF-MAN-EOH-000003)," 2022.

[10] Network Rail, "UKMS Maintenance Manual Issue 2.2 (141667-FAF-MAN-EOH-000004)," 2020.

[11] RSSB, "Lump mass models for legacy pantographs on GB mainline," 2016. [Online]. Available: www.sparkrail.org.

[12] EN 50367:2020, *Railway applications - Current collection systems - Technical criteria for the interaction between pantograph and overhead line*. 2020.