Data driven overhead line equipment (OLE) construction assurance for electrification projects

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Paul Hooper has spent most of his career working on railway electrification projects. He joined BR as a graduate where he worked on the East Coast Mainline electrification. He has since progressed through many roles, including five years in Hong Kong working for MTR Corp. In recent years he has focused on providing technical support to clients from early project conception, design, testing and commissioning and asset management/ renewals whilst promoting the case for further railway electrification as a means to achieving net zero.

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Brad joined Atkins in 2016, in the Overhead Contact Systems (OCS) engineering team working on structural modelling and survey data analysis. He has since transitioned into a digitally focussed role, concentrating on key design automation and survey data processing technologies. Brad now leads software development teams for multiple rail products, including the OLE Static Analysis Toolbox (OLE StAT) in collaboration with Network Rail.

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Simon started in the rail industry in 1999 at Atkins Rail, and has progressively worked in design, construction planning and delivery and design management. Simon has undertaken several key roles within projects, notably Contractors Engineering Manager for a £320m Electrification project on Midland Mainline. Simon was accountable for all design, build and Entering Into Service the Electrification system; 192STK spread over 202 OLE wire runs. He was accountable for providing the assurance to enable the test train to be run. Simon has recently been promoted to the board at SPL Powerlines UK and continues to push Electrification best practise both within his current projects, within SPL and to the industry.

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Adam is a Chartered Engineer and has been working in the rail industry since 2008. Adam has led and managed teams to deliver a wide range of overhead line electrification (OLE) projects through all stages of design delivery globally overseeing the development and deployment of innovative design automation software tools. Adam has been utilising his experience of developing and implementing digital innovation as part of the Central Rail Systems Alliance innovation team with a strategic focus on digital transformation, and in particular introducing a novel OLE digital asset management tool into Network Rail.

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Kevin joined Network Rail in 2006, working in the National Specialist Engineering team dealing with Infrastructure Monitoring. He progressed to Principal Engineer within Network Rail's Technical Authority and is Network Rail's leading expert in trainborne Infrastructure Monitoring. Kevin is a Fellow of the PWI and IMechE and is currently Technical and Engineering lead within the Infrastructure Monitoring programme. This programme is responsible for defining the future strategy for Infrastructure Monitoring within Network Rail and the future Great British Railways.

INTRODUCTION

UK's commitment to become 'carbon-neutral' by 2050, together with the Department for Transport's, (DfT), aspiration to remove diesel-only traction from UK railways by 2040, is pushing towards significant expansion of the existing electrified network.

The Midland Mainline Electrification, (MMLE), Key Output 1, (KO1), London 2 Corby, (L2C), infrastructure project has delivered 40km / 192STK, (Single Track Kilometres), of newly electrified infrastructure from Bedford to Kettering and Kettering to Corby, using the high-and low-tension derivatives of UK Master Series, (UKMS), overhead line design range respectively. A novel approach to construction assurance and system validation has enabled an unprecedented, for the UK, clean authorisation with no conditions for the completed infrastructure network.

The lessons learned together with the added benefits to risk management, commissioning safety and hand-over asset condition reports can significantly improve the current construction assurance processes, and enable the deployment of a systematic monitoring and predictive maintenance regime as part of a successful rolling programme of electrification.

THE CHALLENGE – ELEMENTS OF THE DESIGN, MANUFACTURING AND CONSTRUCTION ULTIMATELY AFFECT THE PANTOGRAPH TO OLE DYNAMIC INTERFACE PERFORMANCE

At the core of any new OLE infrastructure installation lies the safety, reliability and resilience fundamentally driven and characterised by the pantograph to OLE dynamic interface. Whereas the pantograph type test requirements, [EN 50206-1:2010], and conformance to standards [NTSN-ENE:2021], is common across all systems the as-fitted OLE wire profile relative to track after installation ie wire height, (vertical distance), and stagger, (lateral distance), is responsible for maintaining a uniform contact interface performance across the entire installation. Traditionally, manual surveys, generally via track mounted Height & Stagger laser gauges, are used to measure the height and stagger from the track centreline of suspended catenary and contact wires relative to the track at the beginning and centre point of every span.

The OLE design is governed by a number of system basic design principles which aim to maintain interface performance, proportional to speed, within the specified contact force criteria for different characteristic design features, such as open route, wire gradient, reduced system height, overlaps, cross-overs, etc. The system basic design also dictates as-fitted system tolerances, (geometric constraints), for both the design and construction teams to work within in order to maintain the interface performance. These tolerance bands are used to assure the construction against the manual height and stagger survey, generally universally ±15mm in height and stagger to the design values.

The overall tolerance build-up will affect the OLE system/pantograph interface with excessive statistical variation of the contact forces or with distinct local 'hard spots', with the potential to exceed specified requirements. Standards require physical dynamic force testing of the as built infrastructure in order to prove compliance, using expensive and disruptive test trains. Traditional methods for assessing the quality of installed OLE does not provide the level of detail required to ensure the equipment has been installed within tolerance and to demonstrate compliance with standards.

This typically results in problems being identified by the test trains requiring revisits to site to make adjustments to the infrastructure very late in the process. This is a particularly expensive way to pick up any rework / snagging in the construction process and, until MMLE K01, resulted in conditions being added to the project authorisation notice.

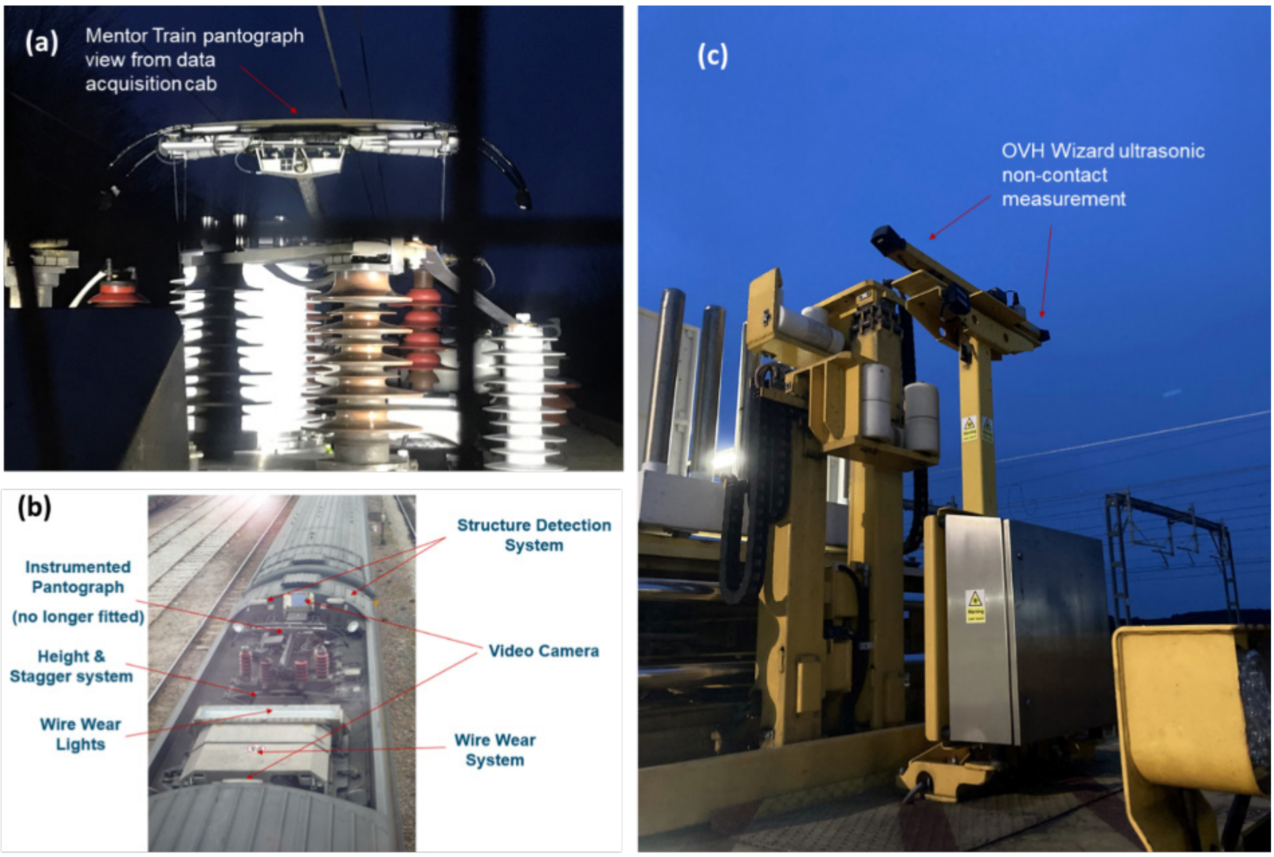

Figure 1: (a) Mentor contact interface testing NR Service train using a single BW HSA pantograph up to 100mph (tethered pantograph view from within the data acquisition cab), (b) New Measurement Train (NMT), non-contact wire profile monitoring height and stagger at ~250mm increments up to 1000Hz and (c) OVH wizard equipment mounted on the HOPS train monitoring height and stagger at ~500mm increments up to ~24Hz.

THE SOLUTION

A novel approach was used on MMLE KO1 to minimise risk and accelerate the assurance and testing process. The KO1 project used UKMS 125, (max. speed 125mph) in the section from Bedford to Kettering and UKMS 100, (max. speed 100mph) from Kettering to Corby. These are both simple catenary systems from the UKMS range but had not previously been validated to demonstrate compliance with the National Technical Specification Notices, (NTSNs). As a result, the system validation process and commissioning of the OLE progressed in parallel.

The detailed OLE design was based on an absolute coordinate Snakegrid system which enables a high accuracy and low distortion digital visualisation of the entire asset. An early assessment of the design, manufacturing and installation tolerances identified the opportunity to progressively monitor the overall system tolerances at each project stage.

TAKING COGNISANCE OF TOLERANCE BUILD UP EARLY IN THE PROCESS – SPAN LENGTHS

The effect of design span length rounding to the nearest metre, (±1m) was drastically improved by working in an integrated digital twin environment and accounting for the along-track impact of boom structures, such as Twin Track Cantilevers, (TTCs) and position of drop tubes on booms, to the resulting span lengths. Additionally, dropper allocation tables with 0.1m increments were introduced for the purposes of the project, thus reducing the design span length tolerance to ±0.1m overall.

The OLE structure installation impact to the resulting 'actual' span was broken down to pile installation tolerance and cantilever rotation. The pile installation tolerance was determined by the project to 75mm radius around the specified location, (141667-FAF-MAN-EOH-000003 2017: UK Master Series Installation Manual, Issue 1.2), and combined to the ±20mm accuracy of the GNSS equipment linked to permanent base stations transmitting corrections using a mobile network, provided by Leica SmartNet. The new GPS coordinate position for the out-of-tolerance installed piles was converted back to the Snakegrid coordinates and implemented into the 3D design before final dropper allocation.

It was also considered that two track cantilever, (TTC), boom rotation, particularly at the outermost drop tube support, could affect the 'actual' span length to ±0.56m. The same effect on portal support structures is very limited because the boom rotation is governed by the pile installation which had a 95mm radius tolerance and was therefore ignored.

Dropper construction tolerances were maintained to ±5mm by off-site fabrication and the use of in-house jigs to ensure consistency. A further construction approach was taken to improve along-track dropper distribution. Traditionally, when a registration arm heel

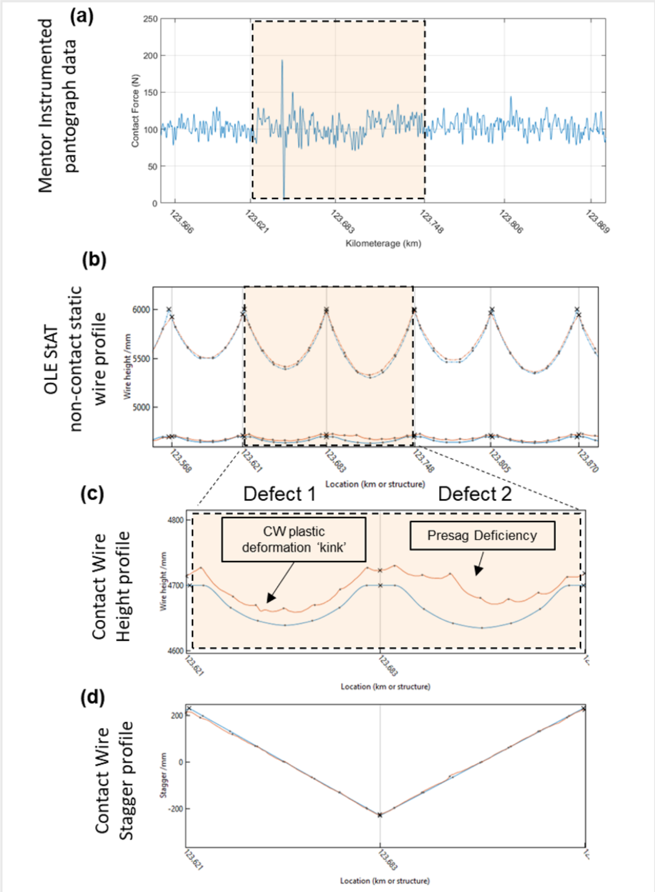

Figure 2: Train borne data overlay indicating, (a) interface force measurements, (Mentor BW HSA @100mph), and, (b) static wire profile exceedances, (OLE StAT analysis), at a specific location. (c) Defect 1 is a permanent wire deformation or 'kink' which results into a significant contact force trace on the Mentor Data. Defect 2 is a presag deficiency of the CW profile due to a dropper length allocation issue. The Defect 2 effect to the Mentor data is visible, however, the overall impact to the interface performance is not significant. (d) Stagger data appear to have a good correlation between design and as-built profile.

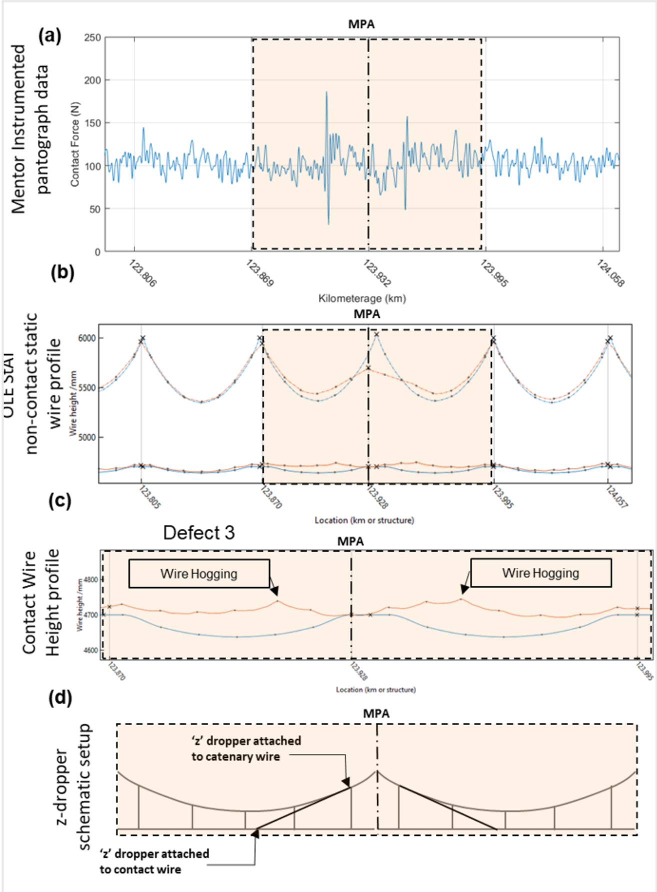

Figure 3: Train borne data overlay indicating the impact to the interface force measurements, (a), (Mentor BW HSA @100mph), and static wire profile exceedances, (b&c), (OLE StAT analysis). Defect 3 is significant wire hogging due to the z-dropper setup, (d). The force applied during setup has an 'axial' and 'vertical' component resulting in lifting of the contact wire.

setting is not achieved, the droppers are moved along-track to get the correct heel. The new approach considered that droppers spacings were absolute due to the impact to the dynamic interface performance, therefore heel settings were adjusted instead. In some cases, approval was gained from the Network Rail Safety, Technical & Engineering section to adopt increased heel setting tolerances, (for high radial loads).

As a result the impact of design, manufacturing and installation tolerances was minimised in the successive stages of the project, thus enabling an optimised wire profile installation which is the key to the system interface performance with the pantographs. Additionally, the digital delivery and the data-base style design implementation and verification can further enable and support any prospective digital asset management requirements throughout the lifecycle of the asset.

STATIC WIRE PROFILE DEFECTS

As part of the Form E Certificate specified within the Network Rail Standard NR/L2/ELP/27311:2020, a Heights & Staggers survey is required across all the installed wires that are within the pantograph head reach. The analysis of the static OLE wire geometry level of conformance to the basic design provides a clear indication of the entire system setup which will interface with the pantograph. The deviation from the system intended geometry highlights potential locations where the pantograph interface performance is likely to be affected by a poor OLE setup. Some of the regular root causes of measured wire profile deviation are:

- Wire 'kink': Contact wire bent out of shape during the installation process.
- Wire tensions: Auto-tensioning Devices may be incorrectly set having an effect on wire presag shape and wave propagation speeds at the interface with the pantograph. The latter effect is more significant at speeds above 100mph.
- Dropper along-track location: a tolerance of ±0.5m is required in the UKMS design manual, (141667-FAF-MAN-EOH-000003) and is affected by a number of factors such as 'actual' vs design specified span length and dropper installation strategy. For instance, in a 51m actual span that was designed as a 50m span with the distance from the support to the first dropper specified at 5m, the last dropper distance to the end of the span will be 6m. Effectively, the result of this is a non-symmetric contact wire profile and non-uniform load distribution across the droppers.
- Dropper lengths: Dropper lengths are calculated based on the catenary wire sag profile and their design position within the span. The manufacturing tolerances are normally kept under 5mm and have a minor effect to the static wire profile. The position of the dropper along the span is significantly affected by the catenary wire profile. An ideal dropper at 15m from the start of the span is 30mm longer than required when it is located 16m from the span start. The same phenomenon occurs when catenary support height variation results in the low point of the catenary wire shifting away from the centre of the span.
- In-line insulator components: insulator components such as Section Insulators and Neutral Sections are necessary to enable the safe electrical operation, (electrical distribution), and maintenance of the system. These components are spliced in and are usually heavier and stiffer than the wiring they replace. As a result, they influence the profile and create 'hard spots' in the parts of the system where such components are installed.
- Cross-over wires: Cross-overs are important components that enable the rail network to operate. The cross-over wires are usually affected by the added weight of section insulators and often absolute height variation between adjacent tracks. If not set up correctly there is a risk the crossing wire, (merging wire), sags to a lower height in relation to the main wire which can result in poor performance or significant de-wirement risk.
- Overlaps: Overlaps are transition spans between adjacent wire runs. The setup of the wires enables the pantograph head to remain in contact with both in-running and out-of-running wires within the specified section of the overlap span. The setup of overlap spans requires a <50mm circumflex to be achieved at the contact wire resting position. Also the gradients at the overlap and the adjacent spans have to be minimised and remain within the system specifications.
- Additional wires added for electrical requirements: electrical jumper cables are installed connecting the contact wire to the catenary wire and other switching components in the overhead system. These often introduce 'hard-spots' to the interface if they are not installed correctly.
- Additional wires: additional wires, known as "Z-droppers", are introduced on some systems near Mid-Point Anchor, (MPA), locations to prevent the along-track migration of the contact wire relative to the catenary wire. The arrangement of the Z-dropper cable can sometimes result in excessive hogging, (lifting), of the contact wire in the middle of the span resulting in 'presag' deficiency. When combined with the wire splicing arrangements onto the contact wire it often impacts the dynamic interface performance.
- Wire height maximum limits: the height limits might result in pantograph Automatic Dropper Device, (ADD), activation when maximum height thresholds are breached.
- Wire stagger maximum limits: excessive stagger might result in the pantograph losing contact with the contact wire resulting in entanglement and de-wirement.
- Gradients: wire gradients relative to track and in absolute coordinates, as well as in adjacent span locations, are often critical to the dynamic interface performance. The shifting of the contact wire centre of mass, (low point), at steep gradients and the vertical wire displacement at localised gradient transitions in open route sections due to track movements or other factors are often the root causes of interface performance issues.
- High-resolution construction assurance

The contractor for the installation on MMLE KO1, SPL Powerlines UK, introduced an alternative approach which offered much more insight to the as-fitted wire profile conformance after the entire OLE system was installed. This approach provided assurance and prioritised snagging activities prior to physical dynamic force

	Date	From	To	Type	Contact height	Stagger	Catenary height	Gradient	In-span deviation	Support deviation /m	Missing droppers	Pre-sag /mm
None	30/07/2020	123.383	123.439	Open route	4699	211	4950	1:-9485	6mm	-7mm	0	57.0mm
None	30/07/2020	123.439	123.504	Open route	4693	-222	5944	1:7131	4mm	-7mm	0	64.0mm
Monitor	30/07/2020	123.504	123.568	Open route	4702	223	5795	1:64611	14mm	3mm	0	83.0mm
None	30/07/2020	123.568	123.621	Open route	4703	-204	5922	1:4784	5mm	14mm	0	58.0mm
! Defect 'kink'	30/07/2020	123.621	123.683	Open route	4714	210	5950	1:6892	3mm	23mm	! CW 'kink'	68.0mm
Defect 2 Presag	30/07/2020	123.683	123.748	Open route	4723	-225	5977	1:-16374	17mm	23mm	0	49.0mm
None	30/07/2020	123.748	123.805	Open route	4719	223	5991	1:-9418	6mm	19mm	0	59.0mm
None	30/07/2020	123.805	123.870	Open route	4713	-218	5961	1:6547	3mm	23mm	0	72.0mm
! Defect 3 MPA	30/07/2020	123.870	123.928	Open route	4723	219	5943	1:-2600	! 32mm	23mm	! Z-dropper	! -23.0mm
! Defect 3 MPA	30/07/2020	123.928	123.995	Open route	4701	-184	5699	1:3973	14mm	18mm	! Z-dropper	28.0mm
None	30/07/2020	123.995	124.057	Open route	4718	241	5961	1:10250	5mm	24mm	0	65.0mm
None	30/07/2020	124.057	124.121	Open route	4724	-227	5964	1:-3068	10mm	24mm	0	50.0mm
None	30/07/2020	124.121	124.179	Open route	4703	228	5967	1:3237	5mm	21mm	0	61.0mm
None	30/07/2020	124.179	124.241	Open route	4721	-212	5996	1:1234	17mm	21mm	0	43.0mm
None	30/07/2020	124.241	124.307	Open route	4771	216	6029	1:804	26mm	11mm	0	53.0mm
None	30/07/2020	124.307	124.369	Open route	4853	91	6061	1:1951	6mm	5mm	0	65.0mm

Legend

- Warning information for this area is not available, usually due to the survey data being invalid or missing.
- There are inconsistencies in the survey data that may become issues in the future and should be monitored for changes.
- The survey data indicates that there are issues that may affect performance.
- ! Significant issues have been detected that may significantly affect performance or lead to a safety incident.
- Issues detected that pose an immediate risk to safety.

Figure 4: 'Traffic Light' dashboard OLE StAT output extract corresponding to the wire run with Defects 1-3.

testing using test trains. The approach previously implemented on the Great Western Electrification Project, (GWEP), helped to identify wire profile defects before the introduction of pantographs using a train-borne, non-contact, high-resolution wire profilometry mapping technique. The purpose was not only to spot check the wire conformance to the design, but to gain a continuous uninterrupted view of the suspended wire profile across the entire installed system, not just at the support and mid-span locations checked using tradition measurement methods. The aim was to analyse the static wire profile mapped on the main tracks at a dropper-by-dropper level of granularity to ensure that the wire will always be within the pantograph interface tolerances, (min/max lateral and vertical limits), and identify wire profile deviations within each span that will potentially impact the interface with the pantograph at increasing speeds. The new approach significantly accelerated snagging activities prior to introducing pantographs by focusing on pantograph to OLE interface specific issues and providing comprehensive rectification guidance.

The wire profile acquisition in KO1 was undertaken using the OVH Wizard [D. Wehrhahn] ultrasonic equipment mounted on the High Output Plant System, (HOPS), train operating with 2 channels at 24Hz acquisition speed. The ultrasonic operating principle of the OVH Wizard provides a wide region of interest and can simultaneously map the contact wire and catenary wire, (up to 7m above rail level), but it is limited in terms of the acquisition speed. For the purposes of the high-resolution analysis required, the average speed used during acquisition was 15mph with maximum speed limit up to 20mph (Figure 1 (c)).

For the purposes of the wire analysis, OLE Static Analysis Toolbox, (StAT), was applied to all the mainline wire runs. OLE StAT is a high-resolution static wire profilometry analysis software that has been developed by Network Rail, Atkins and Train-Rail Infrastructure Solutions (T-RIS). The principle of the software is that the contact wire should be slightly distorted around the dropper locations as a result of the droppers supporting the weight of the suspended wire. The vertical extent of these distortions is dependent on the dropper position in the span, the contact wire bending stiffness and tension and weight supported by each dropper. This can be identified using signal processing and 'peak' finding techniques, (Baimpas et al.). By identifying the along-track location of the dropper from induced peaks on the wire, the vertical wire conformance to the intended design wire profile can be correlated.

TRAIN BORN DATA ANALYSIS AND CORRELATION

A combined data analysis and correlation has been applied to map the complete installed wire profile and quantify the impact of each exceedance to the dynamic interface performance of the pantograph:

i. Non-contact static wire profile analysis using OLE StAT based on OVH Wizard data on the main lines – see Figure 1 (c)
ii. Dynamic Interface data from instrumented pantograph testing with MENTOR test coach (Single BW HSA @100mph. Instrumented by DB Systemtechnik) – see Figure 1 (a).

A set of combined results with existing static wire profile defects, (OLE StAT), overlaid with interface forces, (Mentor), is illustrated in Figure 2. Figure 2(a) shows the dynamic interface data, (Force - N), with the OLE support locations with existing exceedances highlighted. Figure 2(b) presents the OLE StAT analysed static contact and catenary wire profile, aligned with the Mentor data. The OLE StAT analysis overlaps the basic design intended wire profile, (blue), to the as-built wire profile, (orange), for both catenary and contact wires. The identified dropper locations are highlighted on each wire respectively. Figure 2(c) illustrates a close-up to the contact wire profile only at the locations where Defects 1 & 2 have been located. Defect 1 is a permanent wire deformation or 'kink' which results in a significant contact force trace on the Mentor Data. Defect 2 is a presag deficiency of the contact wire profile due to a dropper length allocation issue. The affect of Defect 2 on the Mentor data is visible to a trained eye, however the overall impact to the interface performance is not significant. In the above example, Defect 1 results in a near zero interface force measurement which is likely to incur loss of contact at higher speeds or multiple pantographs. The nature and magnitude of the defect would not have been identified by Heights and Staggers surveys, but is identified due to the high-resolution analysis and the data overlay. Defect 2 results in a 49mm presag instead of a 65mm which does not affect the overall system performance despite exceeding the UKMS 100 system installation tolerances, (vertical and along-track installation tolerance as per 141667-FAF-MAN-EOH-000003 2017).

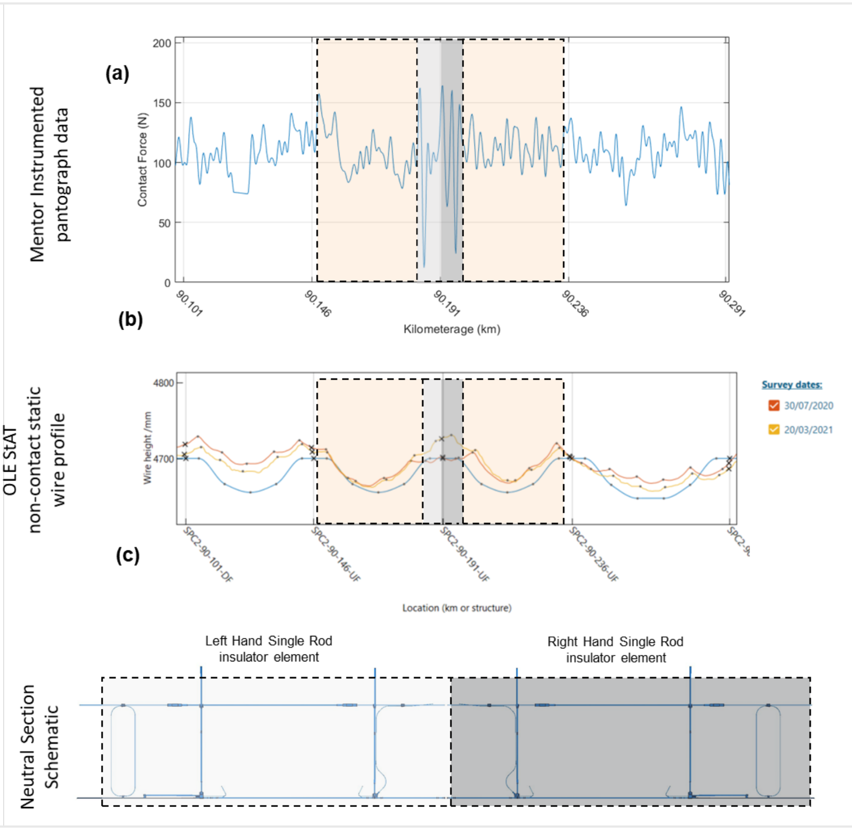

Figure 5: Arthur Flury Single rod Neutral Section, (c) installation on the MML Down Fast showing the resulting impact to the interface contact force collected by MENTOR, (a) and analysed static wire profile, (b) using OLE StAT.

The data analysis is therefore crucial to identify any critical locations in tandem with quantifying the performance impact, which can be beneficial to monitor and maintain the infrastructure at later lifecycle stages.

Figure 3 introduces the combined analysis and correlation between static wire profile deviation and the resulting dynamic interface performance for MMLE at a Mid-point anchor, (MPA), location. Defect 3 is a noticeable hogging of the wire as a result of a z-dropper arrangement installation. The additional wire connects the catenary wire to the contact wire either side of the MPA, as illustrated in Figure 3(d) schematic. The additional wire is also attached to the droppers that it transverses and 1kN pretension is applied. The purpose of the z-dropper is to prevent along-track migration of the contact wire relative to the catenary. The impact of the added weight and non-axial loads into the system affects the wire profile and the resultant interface performance is clearly evident in the MENTOR data, (the spikes in Figure 3(a)).

OLE StAT additionally offers a high-level dashboard summary of the wire analysis introducing a 'traffic light' system based on the specified installation or maintenance thresholds. The OLE StAT dashboard output in Figure 4 enables a high-level system conformance check, which provides a comprehensive schedule for snagging or maintenance interventions to be passed on to the installer/maintainer. Each row of the dashboard corresponds to a number of selected parameters that are checked and presented. Alarm thresholds can be specified depending on installation or maintenance requirements. Figure 4 presents a small selection of the possible outputs including start and end of each span location, span type, contact height, stagger, catenary height, gradient and presag. Additionally, it presents support deviation which indicates the maximum difference in-height between the design and the actual achieved heights. Lastly, in-span deviation is a gauge of the contact wire profile shape conformance to the system basic design principles separate to the height shift at the supports. Areas with increased standard deviation of the contact force normally indicate that the shape of the OLE differs from the system design principles which is quantified by the in-span deviation parameter.

Defects are classified based on the measurable impact to the static wire profile geometry. The level of static wire profilometry deviation can be directly attributed to the corresponding dynamic interface data collected to instruct and prioritise site-interventions. Therefore, a risk-based approach leads to component specific interventions at distinct locations whereas previous interventions are normally instructed across entire areas. Subsequently, 'boots on ballast' time is significantly reduced with the required intervention supported by comprehensive component adjustment work schedules. Crucially, the improvements directly target the interface performance, and the corresponding benefit can be directly assessed and quantified which further enables the monitoring of the OLE asset throughout its lifecycle.

Several other parameters are available and can be checked and flagged to the asset manager. These can be missing/broken droppers, transition gradients, overlap conformance, location specific design parameters, dropper along-track position and along-track location tolerance, actual span length, lateral deviation etc. Lastly, in the case of OVH Wizard acquisition where both messenger and contact wires are mapped, specific dropper lengths can be identified and issued to the maintainer to enable more targeted on-site intervention.

Figure 5 illustrates another example concerning the introduction of insulator components spliced within the OLE wire infrastructure in the Down Fast at Sharnbrook, UK. Single rod Arthur Flurry Neutral Sections are capable of operation up to 125mph, but they are acknowledged as rigid components with separate allowances in the applicable interface performance criteria specified by the standards for contact force. The static wire profilometry data were collected in July 2020 by OVH Wizard and in March 2021 by Network Rail's New Measurement Train, (NMT). The analysis is carried out by OLE StAT for both data sets. The analysis indicates additional hogging has been progressively added by maintenance teams between the scan dates in order to optimise the dynamic interface performance. The dynamic interface data was collected by the Mentor test train in March 2021. The NMT data enabled an up-to-date view of the system following on-site adjustments post the original installation. The overall forces collected at 100mph with a single BW HSA pantograph are within acceptable limits.

Crucially, this approach provides a high-resolution construction assurance method, introduces a system-based assessment of the accumulated tolerances and can accurately predict the impact to the prospective interface performance. Provided that the system mapping is effectively mandated and specified as an integral part of the installation process, a number of benefits can be readily realised:

- Using a contactless measurement system enables targeted wiring adjustments that directly improve the dynamic interface performance, (mechanical interaction of the OLE with the pantograph), prior to operation with a pantograph. This could potentially prevent catastrophic failure. Additionally, this flexible approach can progress in tandem with construction which will further accelerate later assurance activities, (eg non-contact

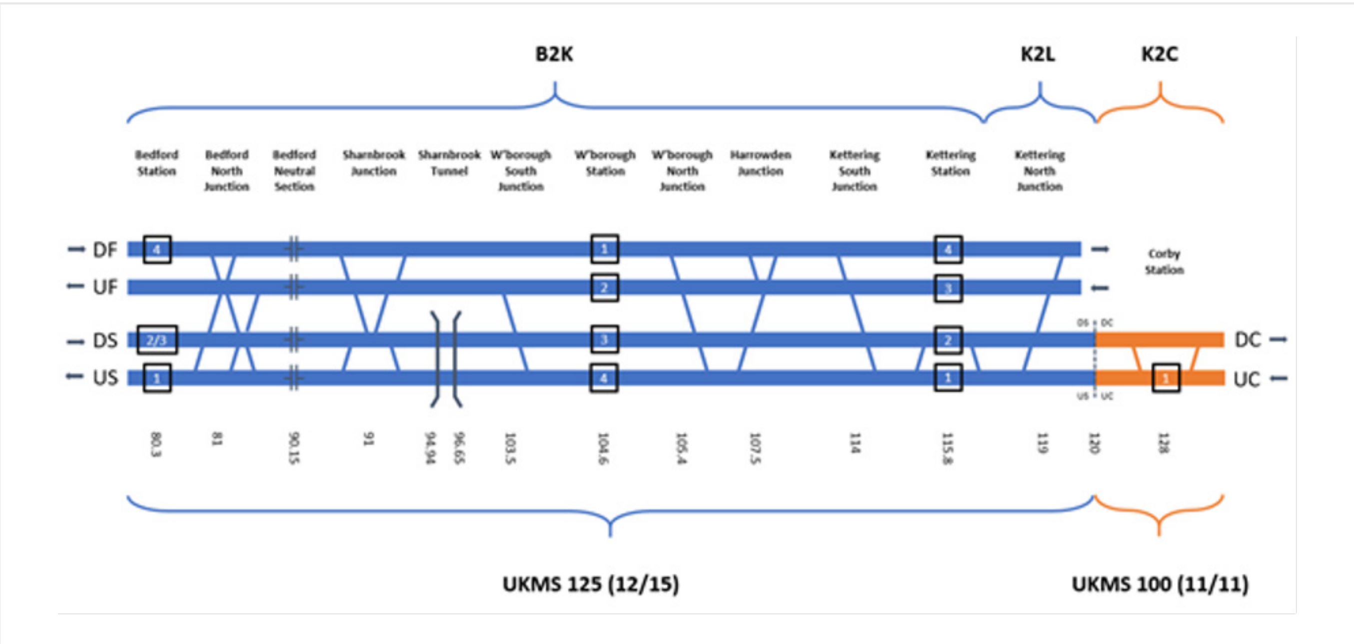

Figure 6 Route schematic showing the tracks kilometrage at crossings, Sharnbrook tunnel, and the transition from the UKMS 125 system to the UKMS 100 at Kettering.

measurements can be carried out by Road Rail Vehicles, (RRVs), immediately following installation as part of the wiring activity);

- Systematic approach to construction assurance based on train-borne data, which will enable faster sign-off for route testing and third-party assurance evidence to the installation quality;
- Gain direct insight to dropper compliance which improves high-speed operation and accelerates on-site interventions. The mapping can be specified to progress in tandem with the installation which will eliminate post completion interventions;
- Map the entire network and hand-over to the Route Asset Manager to be used as the baseline for Asset Condition Monitoring strategy and predictive maintenance.

INTRODUCE PANTOGRAPHS FOR THE FIRST TIME TO THE OLE WIRE ACROSS THE ENTIRE INSTALLATION - MECHANICAL DYNAMIC TESTING

During the early post-installation stage, mechanical dynamic testing was carried out across the infrastructure prior to the energisation using diesel powered locomotives with instrumented pantographs. The testing took place before energisation covering all lines from Bedford to Kettering, (B2K), and Kettering to Corby, (K2C), with progressive speeds at 30, 60 and 90mph, (see Figure 6). The live-force feed was assessed after each pass before a decision that the infrastructure was safe to operate at higher speed. The accompanying information from the OLE StAT analysed wire runs was used for the interpretation of interface forces aiming to associate specific force sample events with specific infrastructure features.

The review of interface force results quickly indicated a number of MPA locations that gave suboptimal performance similar to Figure 3, but the interface forces did not exceed the NTSN limits. Subsequent testing was carried out after removing MPA z-dropper arrangements in specific locations to establish the performance and later enable a decision to maintain, improve or remove the z-dropper arrangements. The purpose of variable speed mechanical testing prior to energisation was to identify and eliminate asset defects and exceedances sooner. Additionally, the ability to overlay static geometry data and dynamic instrumented pantograph data enabled a high degree of confidence during on-board mechanical test data interpretation and a managed risk while attempting high-speed passes.

A similar tactic was previously used during testing at Steventon, UK on the Great Western Mainline, (Baimpas et al.), where instrumented pantograph testing started at 60mph and progressively achieved 125mph. The on-board data analysis was correlated to the Dynamic – Rail System Simulation, (D-RSS), from T-RIS, OLE to pantograph interface dynamic modelling prediction. By achieving sufficient correlation at each speed, the decision to proceed to the higher increment could be made with confidence.

TESTING WITH ALTERNATIVE PANTOGRAPH ARRANGEMENT AND SUBSTITUTE WITH DYNAMIC MODELLING

As an interim validation step in the MMLE KO1 project, instrumented pantograph data from the MENTOR vehicle within a Network Rail test train formation was used to achieve system validation for the UKMS 125 and 100 system derivatives.

The measurements were performed with a single pan formation instead of the multiple pantograph arrangements. However, the results up to 100mph tested indicated that the dynamic interface system performance was at such a level where multiple pantograph operation would be likely to remain within the NTSN and EN 50367 specified thresholds. This decision was supported by the as-fitted wire profile evidence provided as a result of mapping and analysing the entire network using OLE StAT. Therefore, all identified locations with higher contact force traces were cross correlated for the level of compliance to the design and associated installation tolerances.
It was further identified, as part of this exercise, that by simulating the as-fitted wire profile into the finite element interface model D-RSS from T-RIS created a high level of correlation between the measured interface forces using instrumented pantographs and the simulated D-RSS interface performance. The modelling typically achieved correlation greater than 95% even in cases of identified system 'hard spots' such as neutral sections, cross-overs and bridges. It is highlighted that the force correlation achieved is due to modelling with the exact as-fitted asset geometry and implementing into the model various installation set-up, as described within the system manuals. These added features are specific to the UK network and model the OLE and pantograph to a higher level of detail than the models specified by the EN 50318 standard. As a result, these interface models can reliably be used to accurately predict system performance, including for a range of rolling stock formations, pantograph types and speeds, without the need for physical testing.

This approach, if implemented in future, could allow authorisation based on the modelling of the as-built infrastructure instead of expensive, time consuming and disruptive physical testing, de-risking the authorisation process and possibly saving 6-12 months from the programme at the end of a project.

CONCLUSION

Electrification in the UK in recent years has been considered expensive and projects have been beset by problems. There have been many lessons learned and lessons continue to be learned within the projects, but one of the key areas where the industry has struggled has been hand back and authorisation of the new OLE. MMLE KO1 identified this early and through the full lifecycle of the project introduced what could be seen as minor improvements in focussing on construction tolerance at design stage, gaining a higher level of understanding of the as-built asset and testing the asset earlier in the process ahead of energisation. This provided a higher level of confidence and assurance alongside the rigorous physical testing of the infrastructure to contribute towards the electrification project gaining an unprecedented, for the UK in the past 10 years, clean authorisation, with no conditions for the completed infrastructure network.

This work opens up further opportunities to provide greater efficiencies for electrification projects in the UK.

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