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Optimisation of Design and Maintenance of Rail Overhead Systems by Using Modelling and Simulation Tools

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Abstract

Traction overhead line equipment design has developed over decades by a process of progressive adoption of configurations developed through empirical learning. Systems and system components have been set into service with trains of a particular type and at an initial speed of operation. But the relative longevity of fixed traction systems inevitably over time stretches the operational specification as new generations of trains are introduced. This has produced an evolutionary process of development marked by arbitrary rules, which when applied secure the desired dynamic performance. A new approach based on measured data and simulation is described in this work.

Keywords: Traction Overhead Lines, Design, Dynamic Performance, Data, Simulation

1 Introduction

The dynamic performance of the current collection system is influenced by the Overhead Line Equipment (OLE), by the train vehicle suspension, track geometry/quality and by the pantograph. The primary role of the pantograph and the contact wire is to secure good commutation of electric current to power the trains. The mechanical system that maintains good conduction of current across that interface is complex and sensitive.

Energy transmitted from pantograph to the OLE and vice versa must avoid resonant feedback. The pantograph must rise and fall following the catenary geometry and must maintain sufficient uplift force to give good electrical connection. Currents of hundreds of amps are passed through a contact area of a few square millimetres with contact forces between 70 and 150 N. Uplift force from the pantograph must not be so great as to cause the relatively soft central sections of the wire spans to be lifted too much. The vertical and longitudinal forces imparted into the wire and the pantograph head must be contained within a range to prevent stress causing component fatigue or, in extreme, catastrophic damage. The pantograph head must have a low mass and that places limits on the robustness of the assembly.

The design rules applied to the OLE contain much which is based on assumptions. Furthermore, many OLE components can be installed at various positions in span, and whilst many such components are accompanied by rules setting the optimum placing, those rules tend in fact to be arbitrary and largely untested. This results in the application of constraints on designs which are conservative.

Dr John Morris in his work "Design analysis of short neutral section through dynamic modelling of performance" [1] found that it is possible and practical to use modelling and dynamic simulation using Finite Element (FE) methods and to achieve results which can be validated in accordance with EN 50318:2018. Application of the technique to a Neutral Section (NS) installed on the Network Rail test track at Old Dalby revealed a simulation result that correlated with the magnitude of OLE to pantograph forces which were measured during system testing using a DBST instrumented pantograph. The simulation revealed a high force event at the test NS, the magnitude of which was common in both the real world and the simulation results. But, in fact, precise location of the force event was found to be before the pantograph reached the NS. From the instrumented pantograph results this was assumed to be a force resulting from mal-adjustment of the assembly. The simulation however showed it to be a result of wave reflection from the hard spot caused by the mass of the NS assembly. Clearly no amount or accuracy in component installation or adjustment would improve the performance.

The use of a more analytical approach through modelling and simulation has been used to challenge established design rules and has demonstrated the value of dynamic simulations in avoiding expensive and difficult infrastructure interventions. Further development of the approach is being investigated to improve the focus and quality of maintenance in order to avoid in-service faults/incidents and reduce costs.

2 Methods

In their paper: "Data driven overhead line equipment construction assurance for electrification projects" Baimpas, Glass, Benwell, Hooper, Skinner and Doughty [2] outline how a combination of static position measurement of the OLE and slow speed dynamic measurement with an instrumented pantograph has been used to simplify the entry into service testing of 200 km/h OLE on Network Rail Midland Main Line.

For the application described a slow speed pass was undertaken using a non-contact OLE measurement system known as Wizard [D. Wehrhahn]. Wizard is a train-borne, non-contact, high-resolution wire profilometry mapping technique. This provides a continuous uninterrupted view of the suspended wire profile across the entire installed system, not just at the support and mid-span locations on which more traditional methods are based.

Post processing data analysis by OLE Static Analysis Toolbox, (StAT) is applied. The vertical distortion of the wire resulting from the tension, bending stiffness weight of the contact wire at the location of the support dropper wires is determined. Signal processing techniques to find the peak [2] is applied, identifying with high accuracy the profile of the wire and the exact location of all the OLE features. This allows a detailed comparison between the design and the installation. It will reveal individual errors in span lengths, component positions in span and even dropper length errors. This is a useful process to indicate errors in construction, but of course has the weakness that this makes the assumption that the rules of the design are all of equal importance. This would, unchecked, result logically in remedial interventions a number of which would inevitably give no benefit. What is important is therefore to develop an understanding of the significance of the geometry and finished works from the perspective on the influence this has on the dynamic performance. This can only be achieved traditionally by an instrumented pantograph. But, embarking on such testing is both expensive and brings risk that the test will damage, perhaps catastrophically, the pantograph and/or the wires.

Simulation software has been employed in system design for many years. In progressing the Great Western (GW) electrification programme on the Network Rail main line, the proximity of Steventon Road bridge and Stocks Lane public road level crossing presented a need for a change in wire height of 1.78 m over a distance of 360 m. Wire cannot be installed with instantaneous gradient changes, there must be transition spans which reduce the rate of height change. Practical design would have resulted in transition spans at a gradient of 1:350, and maximum gradient of 1:172. The design rules applied on Network Rail infrastructure derive the required gradient by a formula 5 x line speed in mph. The line speed for a gradient of 1:172 is just 35 mph (56 kph), Steventon is at a location where line speed is 125 mph (200 kph). The bridge could not be removed, the level crossing could not be closed.

Simulation work was then applied using the detailed Wizard static data from the installation to define the catenary geometry.

3 Results

The GW main line is a busy Inter City railway. The risk of train and/or wite damage during testing could not be tolerated. It was also not possible to use any vehicle other than a passenger service train, no other option was available. Damage to that train would result in liabilities around £10M. Testing with a pantograph was therefore initially undertaken from a construction train fitted with an instrumented pantograph, running at 40 mph. The data from that test was then accurately overlaid on the Wizard static data. FE simulation was then used to produce projections of the dynamic forces which would be seen at full 125 mph line speed.

Those projections demonstrated that forces would be within TSI at all but one specific location. At that location, a poorly installed dropper was identified as the cause. With that construction error rectified full line speed testing was undertaken with an instrumented pantograph on a passenger train.

The real-world results were within 5% of the simulation results throughout, and the installation was therefore entered into service without speed restrictions.

4 Conclusions and Contributions

The success of the application of simulation at Steventon have demonstrated the potential for simulation to challenge and ease the constraints resulting from long held empirically defined design rules. That is of value in itself.

However, the technique of FE simulation has been applied to give insight into the effect of discrete features and geometries of OLE. This opens a window on the interface analogous to the window which X-ray imagery gives to the medical profession. OLE maintenance is a field in which interventions over the life of the asset are only crudely linked to any real underlying science. Work is now actively being developed by Network Rail to use combined static and dynamic measurement as applied at Steventon to undertake definition of rehabilitation and line speed increase for 50 miles of 40-year-old high speed main line OLE. The method then being adopted to routinely measure and inform the maintenance plan for that equipment.

It is envisaged that this will considerably reduce the cost of the line speed increase and radically improve maintenance performance.

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