Setting the standard for pantograph gauging: An engineering journey

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Colin is the Managing Director of D/Gauge, a company where gauging literally runs in the family. He is a mechanical engineer by training, with over 10 years of gauging experience from a variety of enhancement schemes. He is passionate about nurturing a company culture of innovation and customer focus to ensure that gauging is made approachable and understandable through great presentation and software. Colin loves the complexity and diversity of gauging and leading a team who are constantly developing new services and products to unlock every millimetre of available clearance.

INTRODUCTION

When I joined D/Gauge in 2012, its only focus was supporting industry research adopting new gauging practices. Dr David Johnson, the founder of the company, was focused on debunking the myths surrounding many of the gauging practices being used at that time. He was leading research with RSSB and City University, to transform some of the gauging 'rules of thumb' into data and mathematics that could then be practically applied.

At my time of joining, a critical research project, T942 on pantograph sway acceptance requirements and methodology, was concluding. Its aim was to characterise the sway and future requirements of pantographed vehicles. This was really powerful research. It explored a facet of gauging that had been pushed to one side for far too long. It was well-timed as the Great Western electrification programme was underway and the new impending electric fleets were in the design phase. D/Gauge provided the T942 research project with Pantograph / OLE modelling input.

This project started D/Gauge's adventure and passion with pantograph gauging, leading to a decade of further research initiatives, new gauging approaches, novel projects and the creation of new software tools. The purpose of this article is to provide a whistle stop tour of these major findings and to put in place some signposts for future electrification schemes.

T942: RESEARCH TO UNDERSTAND PANTOGRAPH SWAY (DYNAMIC PANTOGRAPH GAUGING)

Pantograph sway is one of the dominating factors governing electrical clearance and dewirement. It is key in understanding the feasibility of electrifying new track. The ruleset at the time used fixed pantograph sway values which were crudely defined and believed to be overly conservative. The resultant clearances would be overly generous, and the required physical interventions would be larger than necessary. The T942 research project set about to define realistic pantograph sway values that could be consistently and practically applied by both vehicle manufacturers and infrastructure designers alike.

Our approach was to define pantograph gauges in the same way that we defined passenger gauges and vehicle models. The proposed incremental values of sway in 25mm steps of cant, increased the precision from the historical simple categorisation of curved or straight track. The magnitude of pantograph sway was also aligned to the current UK rolling stock for the time.

This method of characterising sway was well established with vehicle builders and to users of specialist gauging software. The approach was labelled dynamic pantograph gauging, owing to its use of dynamic track and wire inputs. The updated pantograph sway limits were issued to the industry in December 2015 and documented in the RSSB standard GMRT 2173.

Alongside pantograph sway, D/Gauge worked closely with Brecknell Willis (Wabtec) and Furrer+Frey to develop a model for the relationship between wire deviation (the lateral distance between the pantograph centreline and the wire) and roll of the pantograph head (the natural rotation as the wire traversed from one side of the pantograph to the other). This is a requirement of the European Technical Specification for Interoperability (TSI).

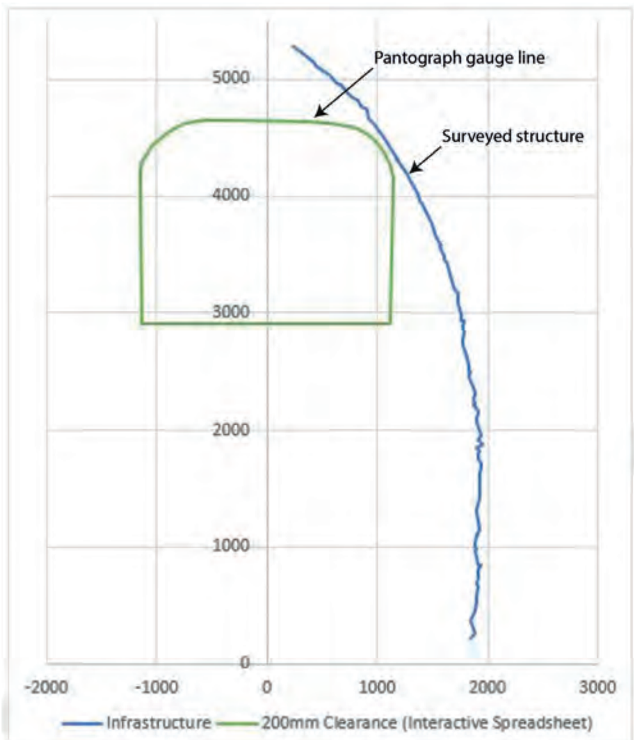

Figure 1: An example of 'pantograph gauging' using T1196 outputs in Excel.

Whilst the maximum limits were stated in TSI standard (60mm of encroachment) at the limit state, these conditions were seldom seen on the UK network. This new relationship reduced pantograph movement as most structures experienced only modest or low wire deviation.

Thanks to these updated models and approaches, significantly more pantograph clearance was demonstrated in most situations. Simply put, most parts of the UK Network are not at the track limit state of cant or the limit state of wire deviation, so the movements were over predicted using the static gauges. The research also demonstrated that pantograph cars swayed less on straight track than previously documented.

Now theoretically proven, my role was to support David in applying the research to the Great Western programme and catalogue the benefits. The programme was using static pantograph gauges to assess electrical clearance. This was seen as a perfect opportunity to compare and contrast against the dynamic approach. Our involvement came at a fairly advanced design stage which documented the track and wire design to a high degree of certainty. Typical gains in clearance were between 50mm and 100mm, but on occasion exceeded 150mm. Arched overbridges, tunnels, signal gantries and awnings benefited the most from the added clearance. Repeatedly, we were able to reduce the level of track lowering or gain additional track maintenance allowance, increasing the maintainability of the design.

Despite being more conservative, the static gauges were easier to use. Electrification design teams predominantly used CAD software to assess pantograph clearance. As we had developed our own internal tools to accommodate the standards and conditions precisely, concerns were raised that this could be difficult to apply in earlier stages of design, as iterations were more frequent and many of the required inputs were unknown or outside the designers' remit.

T1196: RESEARCH TO BALANCING PRECISION AND PRACTICALITY (INTERACTIVE PANTOGRAPH GAUGES)

In 2019, four years following the release of GMRT2173, RSSB launched a new research initiative, T1196: The development of a suite of pantograph gauges, aspired to replace those much-loved legacy static paper gauges. The primary objective of T1196 was to develop a gauge that could: embody the most recent learning on pantograph behaviour; capture the huge variety of wire positions; and be applied without specialist software.

D/Gauge led this research on behalf of the industry with Network Rail as one of the primary sponsors. An interactive gauge was developed for Excel that created an appropriate gauge based on the track and wire inputs. It is intended to support the feasibility and early design but could be used throughout the whole design lifecycle. The output is concise, delivering coordinates that can either be imported into CAD or Excel for further post processing. The project formally concluded in October 2020 with the delivery of the research, and the accompanying spreadsheet is expected to be published in 2021.

It's worth noting that any gauge, by definition, includes conservatism. Gauges are typically a collection of vehicles and/or conditions which by combining them streamlines and simplifies the gauging process. By way of example, T1196 rounds the values of cant excess and cant deficiency upwards to the nearest 25mm, giving some 'wriggle room' for slight changes in future survey changes or realignment tweaks. As a comparison to the previous static gauges, this interactive gauge has significantly less conservatism and it is also compliant to all the latest standards and systems. The clearance requirement could be up to 50mm greater than the dynamic gauge (developed off the back of T942) but is a substantial improvement from the 150mm increased requirements associated with the static predecessors.

To apply either of these gauging approaches, the designer would need the following information:

- Step 1: A structure survey is required with the relative track positions. The centreline of the track acts as the origin of the gauge.
- Step 2: The uplifted wire position is required. The pantograph gauge extends up and widens out until it is constrained vertically by the wire.
- Step 3: The track installed cant, speed and curvature is required. This is used to calculate the track forces and develop the appropriate sway on the pantograph.
- Step 4: Optionally, the stagger of the wire can be reduced from its maximum limits if that design information is available. This will increase the precision of the head roll.

Designers would not need pantograph drawings, specific standards or details of the specific OLE system design beyond expected uplift. Figure 1 demonstrates a typical output from the interactive spreadsheet comparing the pantograph gauge line (shown in green) to a structure survey (shown in blue). Alternatively, the coordinates can be exported for use in other CAD systems and BIM processes.

CASE STUDY: DYNAMIC PANTOGRAPH GAUGING ON THE MIDLAND MAIN LINE

D/Gauge have been supporting Siemens Powerlines and Network Rail with the Midland Mainline electrification project from a pantograph clearance perspective. The remit was straightforward - would dynamic pantograph gauging minimise the wire grading or reduce the track works required to electrify? The North of Kettering route section has a reasonably high number of defining overhead structures including 13 overbridges and 6 signal gantries. The SPL design team had already prepared the proposed wire path, providing maximum staggers and uplifts for the route section. Gauging assessment had been undertaken by Siemens Powerlines using static pantograph gauges and CAD software.

We combined the proposed wire path with the latest infrastructure survey data collected using Fugro's RILA system. A dynamic pantograph assessment was undertaken using our specialist gauging software to calculate the resultant clearances. Track lowering or wire lowering was calculated for locations where normal passing clearance could not be achieved. The final wire and track

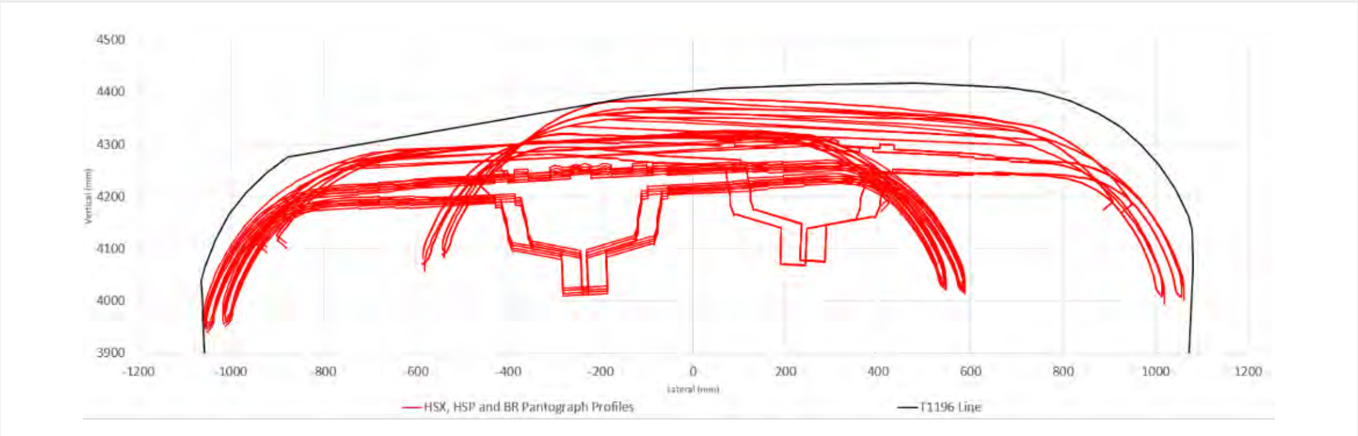

Figure 2: An example of the fitment between the T1196 gauge and the accepted UK pantographs. Room for incremental refinement at future design stages.

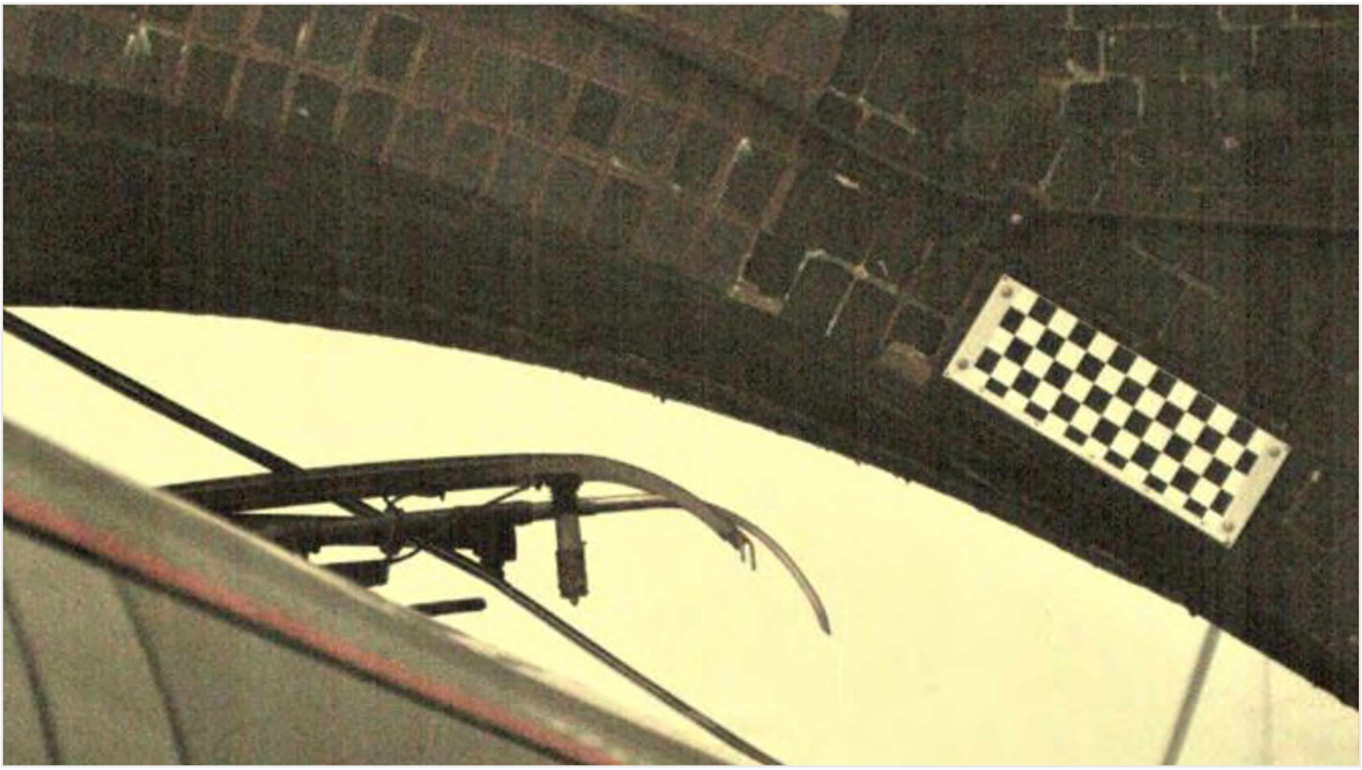

Figure 3: Pantograph clearance verification using a high speed, high definition camera rig, something not attempted previously in the UK.

alignments were optimised and finalised with the SPL design teams based on the local constraints.The investigation has had a positive impact on the project. A problem signal gantry that was foul to the static gauge previously now demonstrated normal clearance to the dynamic gauge. Track lowering was reduced at three arched overbridges by approximately 100mm. A problem arched overbridge south of Bedford with foul physical clearance to the static gauge now can boast normal electrical clearance thanks to the dynamic approach.

T1750: AVOIDING BRIDGE RECONSTRUCTION (ADVANCED PANTOGRAPH MODELLING)

Whilst I support the idea that projects should aspire to design new infrastructure to pantograph gauges, gauging the specific pantographs and the associated rolling stock that will operate could reduce further conservatism and unlock more clearance space. This could provide a necessary lifeline to key sites where clearance to gauges can't be realistically achieved.

Whilst this approach has rarely been used with pantograph clearance projects in the UK, in most cases we have the data and tools to undertake this type of assessment. It would require the use of multibody simulation software (such as VAMPIRE™) to understand the dynamic behaviour of the pantograph cars and high-definition models of the different UK pantographs, the majority of which have already been modelled. Figure 2 demonstrates an example of this conservatism against a current UK pantograph for a given set of track conditions.

To demonstrate this approach, D/Gauge led a successful innovation competition bid under the remit to consider gauging technology to avoid bridge reconstruction when electrifying. One aspect of this project was to quantify the benefit of applying pantograph models instead of pantograph gauges. The project focused on Overbridge 43 on the Old Dalby test track, a known tight structure with 99mm passing clearance to the latest pantograph gauges.

Figure 4: Clearing Actual Pantographs - An example of the electrical clearance at Old Dalby and actual rolling stock.

A new pantograph model was created with the vehicle sway reflecting the appropriate vehicle (in this case a Hitachi Class 800) and the pantograph profile, collector and behaviour reflecting the appropriate pantograph (in this case a Brecknell Willis HSX). The result was that passing clearance increased to 159mm (60mm improvement) which was well within the range of safe working clearance.

In the Old Dalby spirit of innovation, we also attempted to verify this clearance. This verification was intended to prove the mathematics and model behind the approach and provide confidence to the industry. The challenge of accurately capturing and measuring a pantograph passing a structure at 125mph was something that we believe no one else has attempted, maybe for good reason. In partnership with 42Technology, we used high speed optics to capture the moment the pantograph entered the portal and digitise the clearance. Over a number of days, we successfully collected a modest sample of data to verify that the pantograph clearance was never less than 160mm. This was a fantastic project to be part of and the industry collaboration to collect such data was truly commendable.

Figures 3 is one of the captured images with the Class 800 passing at 122mph. The installed datum plate was used to triangulate and calibrate the passing pantograph position. Figure 4 represents the digitised assessment, using the captured pantograph position and the surveyed structure to inform the clearance assessment.

CASE STUDY: STADLER FAST LIGHT INTERCITY AND REGIONAL TRAIN (FLIRT) WITH BRECKNALL WILLIS MK2 HIGH SPEED PANTOGRAPH (HSP)

D/Gauge supported Stadler Rail Group on a project to assess the compatibility and potential physical clashes between Mk1 and Mk3 OLE infrastructure and the FLIRT train. The train itself was fitted with a Brecknell Willis HSP Mk2 pantograph (with a floating collector head) and was being introduced on the Anglia routes. These older OLE systems were not designed around floating heads and the extra clearance they required. Assessment using the dynamic pantograph gauges would demonstrate physical clashes at the extremes of wire deviation. The question - does the specific rolling stock pose a risk to the overhead equipment?

A detailed model of the HSP Mk2 pantograph was created including the profile, wear characteristics and head roll behaviour. Head roll in this instance was calculated based on the uplift force and spring rates at the connection between the floating head and frame. Inputs were validated and agreed in partnership with Brecknell Willis. The FLIRT pantograph car dynamics were generated using VAMPIRE simulation software. We created a library of Mk1 and Mk3 steady arm models, including installation settings, profiles and uplift response.

D/Gauges's inhouse gauging software was used to assess the pantograph against the range of OLE steady arms using the range of adjustment permitted in the design manuals. The assessment concluded that there were a handful theoretical setup conditions which could cause clashes to occur. Network Rail organised a series of site visits to gather the specific heel settings, stagger settings and track geometry that would lead to clash. Reassessment and minor adjustments in some rare situations allowed the route to be cleared. Figure 5 is an example of the detailed clearance assessment undertaken at one of these critical locations.

The FLIRT vehicles are now operating on the route. Using pantograph specific assessment was a novel way to tackle this new problem and the traditional use of gauges would have led to significantly more scenarios that required review and potentially more retrospective OLE work.

CONCLUSION

Over the past decade, in collaboration with RSSB and other partners in the industry, we have undertaken an enormous amount of research that has been summarised in this paper. Not only has the work been done to bring the approaches in line with the established practices for passenger vehicle introduction, but the industry now has a wide range of tools and approaches, from Excel all the way through to specialist gauging software.

There is more research which could and should be done in this field. In my opinion, this should focus on the specific datasets and models instead of developing further approaches. Uplift is an area for huge opportunity, with the move away from a fixed value likely to improve electrical clearance at the vast majority of the Network. Another area is wind, both in understanding its effect on the overhead system, but also how we categorise and measure it at specific locations. Of course, further research into measuring systems could also help to categorise how wires move and wear over time and further remove the fat in these gauging allowances.

D/Gauge have developed, tried and tested these approaches on a host of electrification schemes and successful projects. We are always looking for innovative ways to apply this technology. If you or your project find that clearance to a static pantograph gauge is driving your design, consider whether the new interactive gauges or dynamic gauging may unlock clearance.

D/Gauge would like to thank our long list of supporters and collaborators that have contributed over the years; Siemens Powerlines, Brecknell Willis, Furrer+Frey, 42Technology, Hitachi Rail Europe, City University, Network Rail and RSSB – Thank you.

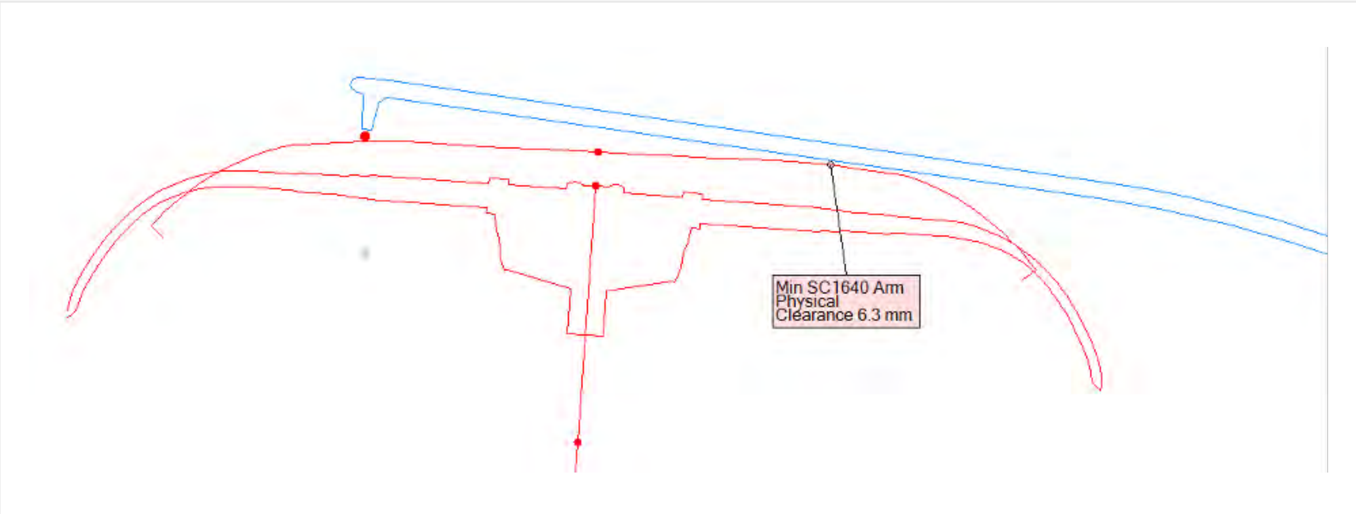

Figure 5: Modelling the interaction between a Pantograph and the Overhead Line Equipment (OLE).

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