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Development of hook and eye fittings for registrations arms on the UK rail network

G. Jones[1], S.M. Barrans[1], H. Kangley[2], M. Newton[2]

[1]School of Computing and Engineering, University of Huddersfield, UK.
[2] Associated Utility Supplies Ltd, Riverside House, Colliers Way, Clayton West, Huddersfield, UK.

Abstract

Associated Utility Supplies (AUS) Ltd conducted a design and development project which investigated the current failure modes of hook and eye fittings, the projected resulted in a new design with improved product life, wear resistance, performance, and reliability. Test results demonstrated that the new design exceeded the loading requirements defined by the technical authority and this project has resulted in a live trial on the UK rail network.

Keywords: FEA, Optimisation, FMEA, Design, Hook, Eye.

1 Introduction

Moving connections in Overhead line equipment (OLE) are usually a hook and eye or ball and socket, to allow the required degree of freedom [1]. Due to several failures of hook and eye registration arm connections used on the UK rail network, Associated Utility Supplies Ltd. (AUS) undertook the development and testing of a new hook and eye connection. A registration arm utilising the hook and eye connection is used to fix the horizontal position of the contact wire [2]. This is essential to ensure the pantograph remains in contact with the contact wire. The contact wire is staggered to ensure even wear of the pantograph carbon, and to allow the overhead line to travel around a curve [3] this stagger results in a lateral load on the registration arm and thus the hook and eye assembly. The registration arm is designed and intended to always be in tension. If the registration arms are under little or no tension, due to locations where there is low radial load, then the hook will chatter in the eye fitting, leading to accelerated wear and erosion as electrical arcing can occur across the fitting [4]. To help combat this, and to help improve product life and therefore reduce the cost of electrification to Network Rail (NWR), clearances between the hook and eye were to be reduced, whilst maintaining overall system geometry, to ensure that the OLE system design remained unchanged. The connection must withstand the worst-case load-case as defined by Network Rail. The current assemblies are either forged/cast aluminium or manufactured from galvanised malleable cast iron as seen in Figure 1. The processes used to manufacture the existing hook and eye fittings typically result in greater design tolerances and thus more clearance required in the fittings.

Figure 1: Hook and eye fitting on a registration arm

Being able to CNC machine the design allows AUS to reduce the tolerances and manage the quality control in-house. AUS sought to optimise the materials used for the separate parts for the application in terms of strength and wear. AUS have experience in the design and optimisation of railway electrification components, OLE, and through their work they are trying to reduce the cost of electrification, whilst enhancing performance and improving product life.

2 Methods

AUS designed and tested their hook and eye fitting in-line with their product development process [5]. This process involves detailed design and optimisation using FEA and hand calculations where applicable; both were used in this project. Optimisation of components allows AUS to reduce waste, using modern design and analysis techniques to maintain strength and reduce the amount of raw material needed and thus waste material generated. Due to known issues with material wear on the current hook and eye fittings, AUS commissioned wear research to allow an informed decision to be made for the material selection of individual components. This research also provided evidence as to the cause of excessive wear in approved hook and eye connections.

The eye's base to tube connection, had previously been tested and analysed by AUS in a different project, so the FEA focused on the stem of the eye fitting upwards. This simplified the analysis and allowed an encastre constraint to be applied to the bottom of the base in the FEA, since stress in the base of the fitting was not a concern. Contact was defined between the hook and the eye fitting, and a mesh control applied around the region of contact. NWR specified a working load limit of 2.65kN with a 2.5 Factor of Safety (FoS) (loading criteria shown in table 1), in the straight direction (the main load case for the intended application), so the design was first analysed with a total load of 6.625 kN applied on the two holes for the bolts in the hook fitting. The hook and eye could then be optimised and reduced in size, to meet requirements, but reduce mass and volume.

	Maximum Permissible Working Load (kN)	Factor of Safety (FoS)	Pass Criteria (kN)
F1 - 25° Load Path	2.65	2.5	6.625
F2 - 60° Load path		1.5	3.975
F3 - Linear Load Path		2.5	6.625

Table 1: Loading criteria

To ensure the design met the load requirements, it was tested as per Network Rail's product acceptance process in accordance with BS EN 50119:2020, using an Instron 3369 50kN universal testing machine. Three custom test fixtures (one for each load path) were manufactured to replace the bottom gripper and align the hook and eye with the load path on the tensile tester. Figure 2 shows the hook and eye installed in the Instron.

Figure 2: Test Set-up/Fixture

3 Results

Optimisation of the design allowed the hook and eye to be reduced in size considerably, whilst maintaining overall system geometry. It was possible to reduce the clearance between the hook and the eye since the parts were going to be CNC machined rather than cast. This decision was made to try to prevent the hook floating in the eye under low lateral load conditions and thus prevent the electrical arcing which is known to accelerate wear and reduce component life [4]. Wear investigations commissioned by AUS, showed that aluminium on aluminium in an abrasive environment, had very high rates of wear, which correlates to the failure modes and in service issues reported by NWR. To combat this, alternative material couples were investigated, and the optimal combination was 316L for the eye fitting and AB2 for the hook.

As predicted, the FEA showed the area of high stress in the assembly as the spine of the hook. No other local regions of high stress were present in the model, as shown in figure 3, This figure shows the stress at the minimum ultimate failure load (2.5 FOS). The high stress region is restricted to the top and bottom surfaces of the spine of the hook and does not penetrate through the section. It was deemed unlikely to cause a failure.

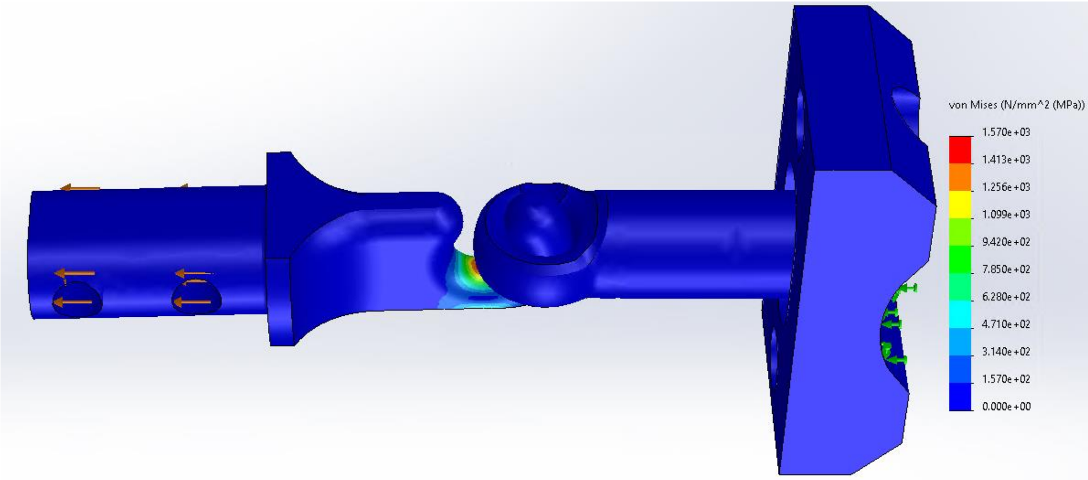

Figure 3: FEA at minimum ultimate failure load

The load was increased, to try to predict an ultimate failure load. Figure 4 shows the area of high stress in the hook (the spine) with 9.5kN applied. The left image shows material above yield (280 MPa), which is almost through the thickness. The right image shows areas above the tensile strength of the material. The inside of the hook is significantly above ultimate failure and thus a crack propagating from this point is highly likely. This crack would reduce the cross-sectional area available to resist the load and thus increase the stress and further failure. So, it was predicted a failure would occur near this load.

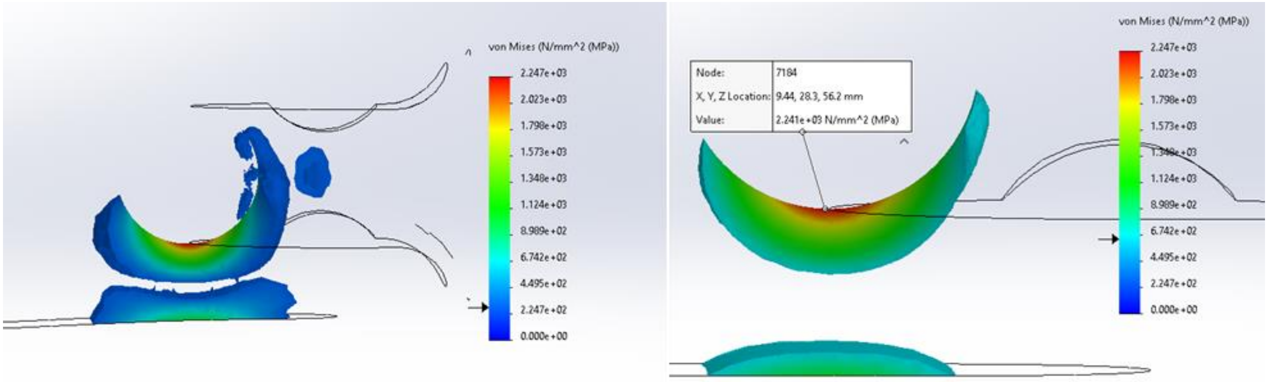

Figure 4: FEA at predicted ultimate failure

Table 2 and figure 5 show the experimental test data. All orientations failed significantly above the minimum ultimate failure load.

F1 – 25 Degree Load Path			F2 - 60 Degree Load Path			F3 - Linear Load Path		
Sample ID	Failure Load (kN)	Failure Mode	Sample ID	Failure Load (kN)	Failure Mode	Sample ID	Failure Load (kN)	Failure Mode
1	9.32	Hook: Brittle Fracture at minor cross section	5	9.64	Hook: Brittle Fracture at minor cross section	9	9.21	Hook: Brittle Fracture at minor cross section
2	9.48	Hook: Brittle Fracture at minor cross section	6	9.44	Hook: Brittle Fracture at minor cross section	10	9.31	Hook: Brittle Fracture at minor cross section
3	9.44	Hook: Brittle Fracture at minor cross section	7	9.53	Hook: Brittle Fracture at minor cross section	11	9.37	Hook: Brittle Fracture at minor cross section
4	9.65	Hook: Brittle Fracture at minor cross section	8	9.51	Hook: Brittle Fracture at minor cross section	12	8.27	Hook: Brittle Fracture at minor cross section
Mean	9.47		Mean	9.53		Mean	9.04	
Mean less 3SD	9.12		Mean less 3SD	9.32		Mean less 3SD	7.7	
FoS	3.4		FoS	3.5		FoS	2.9	

Table 2: Experimental results

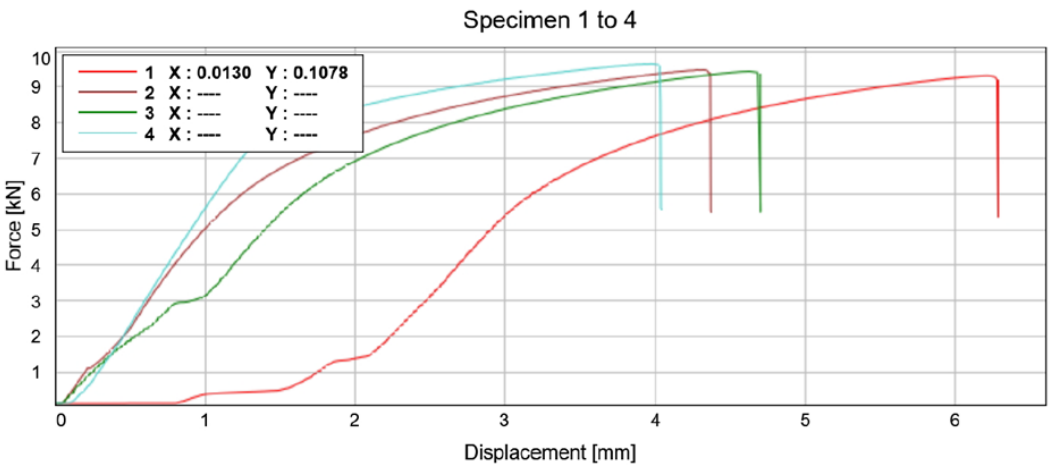

Figure 5: Graph of experimental results

4 Conclusions and Contributions

During physical testing, the failure mode of the assembly was the formation of a crack on the inside of the hook fitting, across the spine. This failure mode was consistent across all orientations tested and was the expected failure during design. Figure 6 shows this failure, and permanent deformation is visible across the bottom edge of the spine. In all tests, the eye and the tube fitting showed no signs of deformation or failure.

Figure 6: Failure mode of the Hook

The average failure load for the 3 different orientations, was between 9.04kN and 9.53kN. The greatest required minimum failure load for the assembly is 6.625kN. The test results exceeded this by a minimum of 36.4%.

The FEA and testing conducted prove the design more than meets the static requirements set out by NWR for the Hook and Eye assembly. It is AUS' belief that through the improvements made to the design in terms of material selection and improved tolerances due to manufacturing methods, the life expectancy of the assembly will be greatly improved. Thus, the ongoing maintenance of the assemblies will be reduced, leading to lower costs to the asset owner.

Further work for the hook and eye includes:

- Full-scale wear testing, to confirm the material selection and prove reliability.
- 12-month trial on Network Rail controlled infrastructure.
- Fatigue testing of the full assembly.

References

[1] G. Keenor, "Overhead Line Electrification for Railways 6th Edition," 2021, p. 140.

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[5] Kangley, Harvey & Barrans, Simon & Newton, Mark. (2019). Making Improvements to Product Development within an SME. International Journal of Materials, Mechanics and Manufacturing. 7. 86-90. 10.18178/ijmmm.2019.7.2.436.