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3 July 2013

Ms Carolyn Griffiths
Chief Inspector of Rail Accidents
Rail Accident Investigation Branch
Block A, 2nd Floor
Dukes Court
Dukes Street
Woking GU21 5BH

Dear Carolyn

Detachment of a cardan shaft at Durham station, 10 April 2011

I write to report¹ on the consideration given and action taken in respect of the recommendations addressed to ORR in the above report, published on 2 July 2012.

The annex to this letter provides details of the consideration given/action taken in respect of each recommendation where recommendations 1 to 6 have been implemented²,

We do not propose to take any further action in respect of these unless we become aware that any of the information provided becomes inaccurate, in which case I will write to you again³.

We expect to publish this response on the ORR website on 19 July 2013.

Yours Sincerely

Chris O'Doherty

¹ In accordance with Regulation 12(2)(b) of the Railways (Accident Investigation and Reporting) Regulations 2005

² In accordance with Regulation 12(2)(b)(i)

³ In accordance with Regulation 12(2)(c)

Initial Consideration by ORR

All 6 recommendations contained in the report were addressed to ORR when RAIB published its report on 2 July 2012.

After considering the report / recommendations, on 3 August 2012, ORR passed:

- Recommendations 3 and 6 to Northern Rail and
- Recommendations 1, 2, 4 and 5 to Angel Trains Ltd and Porterbrook Leasing Company Ltd

Details of consideration given and any action taken, in respect of these recommendations are provided below.

ORR also brought the report and recommendations to the attention of: Voyager Leasing Ltd, Eversholt Rail Group, First Great Western Ltd, Arriva trains Wales and LH Group. As it was concluded that there were equally important lessons for them.

Recommendation 1

The objective of this recommendation is to ensure that the industry completes the work that has already started on reviewing the end float and alignment requirements, as well as the bearing fit as soon as possible and incorporates the relevant changes in a revised overhaul procedure. This recommendation also includes the need for the industry to review the performance of the oil pump particularly in light of the more recent incident at Plawsworth.

The owners of class 14x vehicles, in consultation with suppliers of overhaul services, should review the final drive design, design tolerances and the maintenance processes in respect of:

- end float setting;
- input and pinion shafts alignment;
- fit of the bearings in the housing bore; and
- oil pump performance.

Any required changes identified by the review should be suitably documented and incorporated in overhaul procedures.

This recommendation applies to the modified design of the final drive.

Details of steps taken or being taken to implement the recommendation

1. Porterbrook Leasing Company Ltd in its response on 17 September 2012 advised that:

Porterbrook has been working with owners of 14X vehicles, train operators and industry experts in the field of bearing failures to define the appropriate end float for the input shaft of the SCG gearbox, such that the end float is sufficient to eliminate all risks of thermal runaway associated with loss of radial clearance.

The revised clearance is limited to reduce the risk of:

- *Excessive end float reducing bearing life due to the reduced number of rollers carrying the radial loads.*

- *The input shaft achieving an additional degree of freedom which may result in reduced spine life.*
- *False detection of bearing failure through lift checks carried out by operators.*

The process by which the end float has been set has been an iterative one coupled with the collection of data. The original equipment manufacturer initially specified the end float as between 2 and 4 thousandths of an inch and during the early stages of the investigation the over-hauler was requested to build towards the 0.004” tolerance. Following successful implementation of this request, a further change was made instructing the builders to build between 0.004” and 0.006”. After the introduction of the initial change, further supported by the latter variation, no final drives have failed.

A further potential change to the end float setting is currently being discussed by the SCG Industry Working Group that would see the end float between 0.004” and 0.007”.

During the investigation carried out by the industry into the failure at Durham, deficiencies were identified with the geometric tolerances of the input shaft housing and pinion shaft housing. Investigations regarding appropriate tolerances of these components has identified that they were never initially specified in overhaul documentation. In response to this a contract has been let with the Industry Working Group with ‘David Brown’; expert in the design of gearboxes, who also hold the IPR (Intellectual Property Rights) for the SCG gearbox. ‘David Brown’ has produced a new suite of drawings that define the geometric tolerances for the input shaft, pinion shaft and gear casing. These geometric tolerances take into account the OEM [Original Equipment Manufacturer] information coupled with revision, as deemed appropriate, by ‘David Brown’ given current knowledge of bearing geometric tolerancing. This suite of drawings will be referenced in revised overhaul instructions and it is widely expected that a significant number of the input and pinion shaft housings will require re-work or replacement in order to comply with the new tighter tolerances of these components. This work also considers the varying fits within these housings, again using best practice.

During the course of this investigation the performance of the oil pump with the SCG gearbox has been investigated to understand its operation and limitations. A series of tests are currently being undertaken at ESR Technology that has identified variability regarding its operation. It should, however, be noted that the SCG gearbox has been operating in the railway applications for in excess of 20 years without significant issue relating to bearing failure and furthermore, the failures of the SCG gearboxes, have been focussed at one operator indicating that there is not a fundamental design flaw with the pumps.

The overhaul instruction for the SCG gearbox is currently under review and revision and this will incorporate the current knowledge of the gearbox so as to eliminate as far as reasonably practicable the known failure modes of this equipment.

The overhaul instruction is under the final stage of draft review and it is expected that formal issue will be before January 2013.

After reviewing the information received ORR wrote to Porterbrook, on 15 October 2012, asking for sight of the outcomes of its review.

2. **Porterbrook** in its response on 15 November 2012 advised that:

Porterbrook confirms that when it has completed the review and issued the revised overhaul instruction for the SCG gearbox, it will advise the ORR. The timescales for this are unchanged from Porterbrook's letter of the 17th September.

The revised overhaul instruction will contain a revision history that will provide a brief summary of the amendments made.

Porterbrook will provide a copy of the overhaul instruction to the ORR on its issue.

3. On 18 February 2013 Porterbrook Leasing Company Ltd provided ORR with a copy of the 'Component Overhaul Instruction: Class 14X SCG Final Drive: CR/CI0590: Issue 2.

4. ORR reviewed this document and noted that the figures in section 10.3 Setting Clearances, (which is an extract from an Angel document: Class 14X SCG Final Drive) match the independent report by ESR Technology of February 2013, ESR/NCT/2013/3788/Issue 3: Section 7.0 Solutions.

ORR Decision

5. The revised specification has been published.

After reviewing information received from Porterbrook Leasing Company Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Porterbrook Leasing Company Ltd:

- has taken the recommendation into consideration; and
- has taken action to implement it.

Status: Implemented.

6. **Angel Trains Ltd** in its response on 14 September 2012 advised that:

Angel Trains has engaged ESR Technology to investigate the recent failures of Class 142 final drives and recommend ways of improving reliability and preventing further failures. This investigation work is currently being progressed; however, Angel Trains has introduced recommendations, where practicable to do so, at the earliest opportunity.

Issues have recently been identified with oil pump performance, and ESR Technology is currently undertaking a detailed review of pump performance, this includes establishing whether de-priming can occur in service. The oil pump investigation work is expected to be concluded by end-2012, but is largely dependent on the findings from each phase of testing.

End Float Setting

ESR Technology recommended that the end float setting for the input shaft bearings should be increased to 100 to 150µm. However, if it is subsequently demonstrated that the oil pump periodically becomes de-primed in service a higher setting of 125 to 200µm should be used.

Angel Trains has completed an Engineering Change and put Contract Variation Orders in place to revise the end float setting on overhaul to 100 to 150µm. This is in line with ESR Technology's recommendation and covers all final drives supplied from February 2012.

In light of the issues with the oil pump performance and the earlier recommendation made by ESR Technology, Angel Trains is currently processing the Engineering Change and Contract Variation Orders to take the end float setting at overhaul to 125 to 200µm. Angel Trains is currently waiting for other external organisations to approve this change and, therefore, have no direct control over the timescales for completion. However, it is currently anticipated that these changes will be in place by end-September 2012.

Input and Pinion Shaft Alignment

Angel Trains has engaged 'David Brown', owners of the IPR [Intellectual Property Rights] for the Class 142 SCG final drive, to assist development of the overhaul specification through providing tolerances for the final drive casings and fit of components. The drawings and overhaul specification have now been amended to provide better control of shaft concentricity and alignment.

The revised overhaul instruction for the Class 142 SCG final drive, CR/CI0590, has been completed as a final draft and is currently being reviewed by the industry. Angel Trains anticipate that the final issue of the revised overhaul specification will be fully approved and introduced by end-2012 (it should be noted that Angel Trains do not have direct control over these timescales as other parties are required to approve the revised documentation through their own internal processes).

Fit of bearings in the housing bore

Historically, there were issues with the fit of bearings in the housing bore, however, at the time this was resolved and Angel Trains consider that the current overhaul specification details the appropriate fits with respect to this area. Therefore, no further changes are proposed at this time.

Oil Pump Testing

Angel Trains has engaged ESR Technology to undertake oil pump testing and a significant amount of information and understanding of pump performance has been gained. This workstream is currently on-going and is expected to be concluded by end-2012, but is largely dependent on the findings from each phase of testing.

At present (and as detailed above), Angel Trains is implementing the recommendation made by ESR Technology to take the end float setting at overhaul to 125 to 200µm whilst the oil pump performance is reviewed in more detail.

After reviewing the information received ORR wrote to Angel Trains ORR, on 15 October 2012, asking it to confirm when it has completed its actions to address the recommendation.

7. **Angel Trains Ltd** in its response on 16 November 2012 advised that:

As outlined in Angel Trains' letter of 14 September 2012, Angel Trains has engaged ESR Technology to investigate the recent failures of Class 142 final drives and recommend ways of improving reliability and preventing further failures. This investigation work is now near to completion, with some final testing work on the oil pumps to be undertaken, and remains on target to be concluded by end-2012, as previously advised.

End Float Setting (Final Drive Input Bearings)

As previously advised Angel Trains has completed an Engineering Change and put Contract Variation Orders in place to revise the end float setting on overhaul to 100 to 150µm. This is in line with ESR Technology's recommendation and covers all final drives supplied from February 2012.

In light of the issues with the oil pump performance, ESR Technology had recommended a further change to the end float setting with a revised tolerance band of 125 to 200µm. However, following recent oil pump testing work and considering there have been no failures at the revised setting of 100 to 150µm, the industry working group have agreed to retain the lower limit at 100µm whilst extending the upper limit to 175µm. The tolerance band of 100 to 175µm has been included within the final overhaul specification CR/CI0590. This has been subject to review by the industry and is supported by ESR Technology. Angel Trains is progressing the Engineering Change for the updated specification CR/CI0590 Issue 2 and it is envisaged that this will be approved by end-2012, with implementation in Q1: 2013 through a Contract Variation Order.

Input and Pinion Shaft Alignment

As previously advised Angel Trains has engaged David Brown, owners of the Intellectual Property Rights (IPR) for the Class 142 SCG final drive, to assist development of the overhaul specification through providing tolerances for the final drive casings and fit of components. The drawings and overhaul specification CR/CI0590 Issue 2 have now been amended to provide better control of shaft concentricity and alignment.

The testing has identified that some pumps are more reliable when it comes to priming than others and initial indications are that this seems to be dependent on dimensions of some of the key components. ESR Technology is currently completing some additional tests to confirm their findings regarding pump performance and this workstream is close to being completed. The output will be used to provide additional information for the manufacture and assembly of oil pump components. The overhaul specification CR/CI0590 will be amended and re-issued, as appropriate, to include this information.

ORR Decision

8. The revised specification has been published.

After reviewing information received Angel Trains Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Angel Trains Ltd:

- has taken the recommendation into consideration; and
- has taken action to implement it.

Status: Implemented

Recommendation 2

The objective of this recommendation is to ensure that designers of railway equipment validate any changes to the design of safety critical components.

The owners of class 14x vehicles should review the adequacy of their existing arrangements for ensuring that the suppliers of their equipment validate changes to the design of safety critical components.

Details of steps taken or being taken to implement the recommendation

9. **Porterbrook Leasing Company Ltd** in its response on 17 September 2012 advised that:

Porterbrook, as an owner of railway assets, manages its supply chain to ensure that where changes are made they are recorded and managed. In order to achieve this, Porterbrook has a number of procedures in place that includes management of change, supplier accreditation, supplier management plans and regular product and process audits. These procedures are aligned to RISAS (Railway Industry Supplier Approval Scheme). LH Group Services who overhaul the SCG gearbox is RISAS accredited for this work.

Where changes are proposed by the supply base, these are reviewed by individuals within Porterbrook who have technical competence for the area of change and are agreed, amended or rejected as appropriate. This information is recorded within the Porterbrook asset management data base. Physical configuration of the asset is contained within the records held by the over-hauler.

Porterbrook works very closely with its supply chain and holds regular meetings to identify potential difficulties with the overhaul of its assets and endeavours, where possible, to address these by working with the supplier in developing a solution. Porterbrook therefore believes that it has adequate arrangements in place for the management of its suppliers and the changes that arise from the process of maintaining and overhauling rail vehicle components to ensure continued service operation of its fleet.

10. **Porterbrook Leasing Company Ltd** in a further response on 15 November 2012 advised that:

Porterbrook operates a management of change procedure STD/T2/07. This procedure is used to assess the risk of changes to Porterbrook assets. The procedure has been subject to review internally and reviewed externally as part of the scope of our recent successful RISAS assessment. Porterbrook is content that this process effectively manages engineering risk within its company. Any changes to overhaul specifications/components that LH Group Services (or any other supplier) propose are, as required by contract, submitted with an engineering change submission. The Porterbrook review of the validity and agreement of this documentation is then managed in accordance with STD/T2/07 [management of change procedure] and its contract variation procedure PRO/T2/01. The engineering change process at LH Group Services is within the scope of its RISAS approval and has been subject to review during scheduled Porterbrook audits of component overhaul.

Audits undertaken by Porterbrook of suppliers include within their scope, review of changes to products/specifications and checks that these have been notified through the formal engineering change process operated by Porterbrook.

In summary Porterbrook has regular engineering and contract review meetings with all its suppliers which include any proposed product enhancements/changes that may be identified. Porterbrook has reviewed its contract interfaces and its internal

procedures and is not proposing any amendments to the processes currently employed in its engineering change and contract management.

After reviewing the information received ORR wrote to Porterbrook Leasing Company Ltd, on 7th February 2013, asking it to clarify how the overhaul arrangements permitted incorrect set-up of the outer bearing to go unrecognised.

11. On 18 February 2013 Porterbrook Leasing Company Ltd advised:

Porterbrook confirms that management of change procedure STD/T2/07 was in place covering the period before this incident.

Like Angel Trains, Porterbrook do not directly procure Class 14x final drives from LH Group. This arrangement reflects the nature of the lease arrangements that Porterbrook has in place with operators of 'Pacer' vehicles, with Great Western, Arriva Trains Wales and Northern Rail, all having agreed Spares Access Contracts with LH Group to purchase overhauled final drives directly from them.

The specification for the overhaul of the equipment was and remains a common RoSCO document. In these circumstances any change to the detail of the specification should be agreed with the customer with the associated approval for this change also being submitted to Porterbrook for approval. Notwithstanding this requirement, there is a Spares Management Agreement in place with LH that requires LH to agree any change with Porterbrook before its implementation.

In this case these obligations were not met. Consequently notification of change to the set-up of the outer bearing went unrecognised by both Porterbrook and the Operators purchasing the equipment.

Recognising this weakness, Porterbrook has been working very closely with LH Group in an effort to ensure that this situation does not arise in future. In this regard, Technical reviews between LH Group and Porterbrook focus on proposals for change being considered. Porterbrook will ensure that audits of the supplier focus on change management controls as part of the audit scope.

From the information noted above, Porterbrook would hope it is recognised that the various contractual relationships which exist in regard to the supply chain for the equipment in question. Porterbrook believes that these are adequate if fully applied. This investigation has heightened awareness around these change control requirements, but Porterbrook is confident that these arrangements are fit for purpose and do not consider any further action is appropriate at this time.

ORR Summary

12. Porterbrook confirmed that its management of change procedure STD/T2/07 was in place at the time of the incident and consider it to be adequate; however, it also acknowledged that the obligations placed on the contractor to follow the procedure were not followed.

13. Porterbrook also advised that it has taken measures to prevent a recurrence by ensuring that audits of 'the supplier' focus on change management controls as part of the audit scope.

ORR Decision

14. After reviewing information received from Porterbrook Leasing Company Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Porterbrook Leasing Company Ltd has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: *Implemented*

15. **Angel Trains Ltd** in its initial response on 14 September 2012 advised that:

Angel Trains has a vested interest to ensure that works carried out on its assets are undertaken correctly. In order to control this in a robust manner, Angel Trains has in place a number of formal management procedures.

Management Procedure AT/E01 formalises the process by which Angel Trains manage Engineering Change. As part of normal business activity, this procedure undergoes formal review every two years, with the next such review being due on 26 October 2013. Management Procedure AT/E15 formalises the process by which Angel Trains manage maintenance, including the control and issuing of Contract Variations. This procedure undergoes formal review every two years, with the next such review being due on 1 November 2012.

Angel Trains has a contract in place with Unipart Rail Limited (URL) for the supply and overhaul of Class 142 final drives and wheelsets, with URL sub-contracting the work to LH Group Wheelsets (LHGW). This contract was initially formalised through a Sales and Purchase Agreement (SPA). However, on 1 August 2012 Angel Trains put in place a Heavy Engineering Framework Agreement (HEFA) and Task Form with URL. The HEFA and Task Form are a clearer and more robust contractual arrangement than the historic SPA, being more prescriptive with regards to the process of managing Engineering Change and Contract Variations. The HEFA requires URL to inform Angel Trains of any changes to the supply of components and regular Contract Review meetings are held to discuss and review any proposed changes ahead of formal submission of the relevant documentation. Angel Trains considers that the new contractual arrangement is a significant step forward in process improvement and in the requirements on Suppliers to manage change.

Angel Trains has reviewed the RAIB's recommendation and is not proposing any amendment to the processes that are followed in respect to the Management of Engineering Change, the Management of Maintenance and the implementation of Contract Variation Orders.

It should be noted, however, that Angel Trains hold regular Contract Review Meetings with Suppliers which provides a means of identifying and addressing any issues that may arise in the future.

ORR Decision

16. After reviewing information received from Angel Trains Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Angel Trains Ltd has:

- taken the recommendation into consideration; and

- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: *Implemented*

Recommendation 3

The objective of this recommendation is to ensure that Northern Rail has in place risk control measures to detect impending final drive failures before they occur.

Northern Rail, in consultation with the owners of class 14x vehicles, should develop, validate and implement measure(s) to identify and prevent the onset of failure of a recently overhauled final drive so as to prevent complete failure where practicable.

Note: the measure(s) implemented to address this recommendation may be appropriate to all class 14x final drives.

Details of steps taken or being taken to implement the recommendation

17. **Northern Rail** in its initial response on 6 September 2012 advised that:

Following the initial low mileage final drive failures Northern Rail implemented a control regime to detect such low mileage failures as follows:

Final Drives up to 18,000 miles:

One off check, 24 hours after fitment for input shaft lift, temp sticker check and visual 48 hour checks on-going up to 18,000 miles for input shaft lift, temp sticker check and visual 60mph speed restriction on vehicles In addition to the above, if a vehicle has a fuel point exam at an outstation a temperature sticker check is carried out

Following the later failure of 142003 at Plawsworth in April 2012 the above checks were supplemented with the following:

Oil pump priming check:

Priming checked on fitment of final drive wheelsets to a unit, both old and new temperature sticker checked 24 hours after fitment of a wheelset

These checks have been maintained on all final drives following fitment and are still in place currently.

In parallel with these on depot checks, Northern Rail has been working with the vehicle owners and other industry experts to investigate the final drive failures through an Industry Working Group. Northern Rail believes that sufficient actions are now in place during the overhaul process to prevent the failure of recently overhauled final drives.

These include the revision to the overhaul specification to include current best practice of geometric tolerancing of components, the increase to the allowable bearing end float in the input shaft assembly and the amendment to the process of measuring this end float to ensure that the final drive as shipped from the overhauler has the end float as specified within the overhaul instructions. This includes two separate checks of the set bearing clearance and following assembly of the final drives at the overhaul facility, the finished wheelset is subject to an extensive series of tests that record both temperature rise of the gearbox, gearbox bearings and oil.

In Northern Rail's opinion these actions are sufficient to prevent failures of the input shaft assemblies of SCG gearboxes going forward.

However, following reports of vibration in service a final drive on 144008 (55831) has been found with a failed input bearing on 21st August [2012]. The final drive was at a mileage of 164,000 miles, being fitted on 21st February 2011. This is concerning because the final drive was overhauled around the time of the previous failures, but is well outside the mileage range associated with previous failures.

A Joint Investigation was expedited on the failed final drive from 144008, and this was completed on Friday 24th August [2012]. The investigation confirmed that:

- The inner input bearing had failed and was breaking up, with clear signs of overheating*
- Impression marks were found on the inner bearing race, with cage destroyed.*
- The outer input bearing was intact, but showing signs of wear*
- The oil pump gear was found to have a split pin sheared, although the gear remained on its shaft. Tests carried out suggest the oil pump was working, but at higher speeds there would have been slippage of the pump drive and possible reduced oil pressure*
- The condition of the oil was very poor, with significant grease contamination. Debris was found throughout the drive, suggesting that the pump had operated after the bearing failure.*

It has been concluded that a combination of very small bearing end float (records show that it was set up at overhaul to 2 thou, the minimum of the then applicable set up standard) and inadequate lubrication have combined to cause bearing failure.

Following discovery of this failure an immediate fleet check was issued to carry out lift checks on all Class 14X final drive input shafts, similar to that carried out on low mileage final drives. During these checks, on 22nd August, the final drive nose cone on 55573 (142032) was found to be showing signs of overheating on the temperature stickers. This drive was built 3 days before the drive that failed on 144008, by the same personnel. It was also recorded to have zero lift on the input shaft, which is an indication of very little end float in the bearings.

During the investigation both final drives from 142032 were inspected and bearings were found to be okay, although they did show heavy wear on raceways. They were measured with 1 thou and 0.5 thou clearance, the former one being the one that had high temperature readings. There were a couple of blue spots on the selector fork of former, and it was concluded that there had been inadequate lubrication at some point.

In addition to the above unit, a second unit was identified during the fleet check to have excessive input shaft lift. During the investigation of this excessive lift on 142009 (55600) the measured the bearing end-float was found to be 0.75mm, however when the final drive was stripped it was noticed that this was actually play rather than end-float, as the nosecone had been fitted with a sleeve, which is supposed to be an interference fit, it could be moved easily by hand. There were marks on it indicating that the sleeve had been creeping / spinning. It is likely that it was not seated properly on build, allowing it to move axially. If it had been seated properly, it is likely that the oil seal housing would have kept the sleeve/bearing

assembly in place. This is a new failure mode that has been identified and is one that could lie dormant for a period. It is not yet known which final drives are fitted with sleeves although it is believed that an increasing amount have been fitted in past few years to reclaim the bores. The risk that this poses is twofold; the sleeve could rotate and block the oil ways lubricating the bearings, and being loose it can cause a greater degree of vibration on the cardan shaft, which could increase risks of cardan shaft failures. Also, the axial movement, where great load is exerted, such as when taking power, could stress the oil seal housing bolts. Should these fail, then the shaft could detach.

It has been determined that the development of this failure mode is slow, with the method of detection being a lift check. It is believed that the probability of finding similar failures is low, but still possible.

Following the identification of these three final drive failures during maintenance, Northern Rail has decided to review its current mitigation arrangements and are currently in the process of making the following changes:

1. Northern Rail has instigated a further one-off fleet check commencing Friday 31st August, embracing all Class 14X vehicles
2. Northern Rail has initiated the fitment of existing 19 temperature intervention kits to 'high risk' units, in particular those final drives overhauled during same period as previous failures, which may potentially have limited bearing clearance.
3. Northern Rail is replacing the current low mileage final drives with the following control regime;

From 10th September [2012] Northern Rail is initiating a check of the fleet to complete a lift check, oil sample and fitment of temperature stickers. This will be completed by 24th September [2012].

From 24th September a new check regime will be implemented as follows;

- Fuel Point Exam: Check the temperature sticker
- A Exam: Check the final drive temperature sticker and carry out a lift check
- B Exam: Check temperature sticker, replace temperature sticker, and carry out a lift check
- B Exam: Carry out final drive oil change

Separately Northern Rail is discussing final drive replacement options with the RoSCOs, [Rolling Stock Operating Company] although it is now becoming apparent that a long term replacement final drive is at least 18 months away, so Northern Rail is negotiating with the two RoSCOs to fit the temperature intervention modification across all vehicles. This will provide a continuous monitoring of final drive temperature and a more reliable check of temperature than the current manual checks.

Porterbrook have offered to fund fitment of the temperature intervention modification on their Class 144 fleet, and discussions are in progress with Angel on the Class 142 fleet, which are hoped to be concluded in the very near future. In the event that funding cannot be agreed, we have been working up the business case for fitment of the modification to the Class 142 fleet, and this will be considered for approval if necessary at the Northern Holdings Board on 12th September

Northern believes that the changes to final drive overhaul standards have removed the risk of input bearing failure, but recent developments have indicated that there is a risk of earlier overhauled final drives failing at higher mileages. A control regime is being implemented which will include fitment of a temperature intervention modification in due course, and in the long term final drive replacement with a simpler design is considered to be the optimum solution.

18. ORR met with Northern Rail on 31 May 2012 and on 31 August 2012 Northern provided ORR with:

- 14X Final Drive Failure Mitigation Arrangements report; and
- A fault tree analysis of failure modes

Extract from 14X Final Drive Failure Mitigation Arrangements paper:

2.2) Mitigating measures in place prior to Plawsworth incident

As a result of the Durham incident mitigating controls were reinforced to capture final drives that were 18,000 miles since build and comprised of 48 hour examinations of the final drives for input shaft lift, temperature stickers and any sign of oil leakage.

In addition, a 60mph speed restriction was introduced in order to both reduce the possible probability of failure (to limit heat generation), and the consequence of such a failure.

Checks during Fuel Points were also introduced to examine temperature stickers.

The checking regimes resulted in a number of final drives being removed on a precautionary basis and were subject to a Joint Investigation at LH Group. None of these final drives were assessed to be close to failure, however, useful evidence was collected as part of the overall investigation as some of the final drives inspected exhibited signs which supported theories of causation for the Durham incident.

The use of a temperature intervention modification was introduced to constantly monitor the temperature of the final drive and highlight high temperature deviations to the driver, as the checking regime may not capture all failures due to the rapid nature of failure propagation. This has been fitted to 30 vehicles to date following recent wheel-set changes.

2.3) Mitigating measures in place following Plawsworth incident

Following the incident at Plawsworth, further mitigations were introduced to address initial findings of this incident. These include the following:

- *Oil pump priming test prior to wheel-set fitment in order to assure that the oil pump is primed following handling of both new and used wheel-sets away from the vehicle.*
- *Final drive oil sampling and oil change of the 14x fleet to ensure that the quality of final drive oil is suitable, following evidence of poor condition oil on 142003.*
- *Briefing in relation to the handling of wheel-sets on depot, as the orientation of final drive may have played a critical part in de-priming the oil pump whilst being handled on C4 [overhaul] at Heaton.*
- *An audit of the 14x Final Drive mitigations in place was undertaken by a Technical Safety Auditor on the 14th August 2012 and found that the mitigations*

were being effectively managed by the Engineering department. This provides assurance that the mitigations put in place are being robustly adhered to.

9) Conclusion

All the significant final drive failures have had inadequate input shaft bearing clearance as their root cause.

Improvements to the overhaul specification and introduction of increased clearances from August 2011 has reduced the risk of thermal runaway and associated bearing failure of final drives overhauled since this time.

It was initially believed that the inadequate specification and overhaul processes in place at LH Group Services prior to August 2011 would manifest themselves as early life bearing failures, and mitigation measures have been developed and implemented to contain this risk.

Investigations into the final drive incident at Plawsworth suggest that the oil pump became de-primed during C4 activity and failed to re-prime

Oil pump testing confirms that the pump does not always self-prime easily, but once primed the pump will remain operational in most cases. Mitigations introduced as a result of Plawsworth address the issue of oil pump priming.

The more recent failure of 144008 has demonstrated that in some circumstances, yet to be confirmed, the presence of a low bearing clearance can manifest itself as a cause of bearing failure in higher mileage final drives, so the early life mitigation measures have been supplemented by on-going controls through the monitoring of final drive nose cone temperature, and periodic lift check.

Consideration of alternative final drives has been discussed with the ROSCOs, with agreement being reached to explore further the introduction of alternative final drives as a long term aspiration.

Due to the concern around the robustness of the existing mitigation measures if applied in the long term, Northern is currently working with the ROSCOs to build a business case for the fitment of the temperature intervention modification across the fleet, and fitment now seems likely to proceed from November 2012.

After reviewing the information received ORR wrote to Northern Rail, on 7 February 2013, asking it to advise if its actions to address the recommendation had been completed.

19. Northern Rail in its response on 14 March 2013 advised that:

Fitment of the final drive temperature intervention modification is progressing well, with 179 vehicles now being fitted with the modification (84% of the 14X fleet). The number of 'high risk' vehicles (where enhanced monitoring is in place) has dropped to 3 units and these are being prioritised for fitment as soon as possible.

Full modification of the fleet will be completed by late March 2013, which will then enable removal of the majority of current control measures, with just the periodic final drive input shaft lift check on B exams being retained to detect any residual failure modes not related to bearing failure.

ORR Decision

20. After reviewing information received from Northern Rail, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Northern Rail has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: *Implemented*

Recommendation 4

The objective of this recommendation is to ensure that key design information is made available to companies undertaking work on class 14x final drives.

For class 14x vehicles, vehicle owners in consultation with operators should review whether the necessary technical information for the maintenance and overhaul information of the class 14x final drives is still available and if it is, they should arrange for it to be sourced.

This information should be kept by the vehicle owners and made available to all existing and future operators, maintainers and over-haulers as relevant.

Note: the principle outlined in this recommendation may also apply to other traction and rolling stock equipment and other fleets of train.

Details of steps taken or being taken to implement the recommendation

21. **Porterbrook Leasing Company Ltd** in its initial response on 17 September 2012 advised that:

Porterbrook has in place maintenance and overhaul information to support the continued service operation of its extensive fleet of vehicles. These overhaul instructions are regularly updated to reflect known or emerging issues and where changes are made, these are subject to technical verification by personnel with the appropriate expertise.

This information, however, is distinctly different from the ownership of the IPR (Intellectual Property Rights) for all of its assets and Porterbrook is constrained by the fact that original equipment manufacturers are unwilling to release their IPR to a third party. Whilst ownership of the IPR for all the equipment which Porterbrook owns represents an ideal position, it is also a position that is untenable. Where specific technical information is required to address arising issue with the equipment, Porterbrook will work with the original equipment manufacturer or other technical experts to identify how the relevant information can be sourced so as to address the arising issue.

It should be noted that whilst Porterbrook is a leasing company, approximately half its staff are engineers and these are used to ensure the safe and continued operation of its fleet of rolling stock.

22. **Porterbrook Leasing Company Ltd** in a further response on 15 November 2012 advised that:

With regards to the review undertaken by Porterbrook with respect to the necessary technical information being available for the maintenance and overhaul of 14X final drives it provided the following detail.

Porterbrook has worked in collaboration with Angel Trains Ltd, Operators of 14X rolling stock and the current over-hauler (LH Group Services). The revised overhaul document CR/CI0590 (awaiting publication) has been reviewed by this group from disassembly to inspection, assembly and test. Documentation, both process and product, supporting this process has also been reviewed.

Where concerns have been identified as part of this process, competent organisations have been procured to provide recommendations. Examples of these include ESR Technology, technical experts in bearings, and David Brown Gears (OEM) [original equipment manufacturer] analysis of the final drive with their associated production of new drawings for final drive casing machining requirements. Thus all available expertise and technical knowledge has been used to revise the maintenance and overhaul documentation and hence Porterbrook is confident that this documentation is adequate.

Detailed design and technical information is held by the OEM David Brown who has confirmed that their intellectual property is not for release.

ORR Decision

23. After reviewing information received from Porterbrook Leasing Company Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Porterbrook Leasing Company Ltd has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: Implemented

24. **Angel Trains Ltd** in its initial response on 14 September 2012 advised that: *Angel Trains continue to work with the industry in taking steps to ensure that critical design information is made available to companies undertaking overhaul work.*

In collaboration with the industry (including other vehicle owners, train operators, component suppliers and technical specialists), Angel Trains is nearing completion of a revised overhaul instruction for the Class 142 SCG final drive (documented in CR/CI0590). This has been completed as a final draft and is currently being reviewed by the industry. Angel Trains anticipate that the final issue of the revised overhaul specification will be fully approved and introduced by end-2012 (it should be noted that Angel Trains do not have direct control over these timescales as other parties are required to approve the revised documentation through their own internal processes).

As part of the process of updating CR/CI0590, the entire final drive overhaul process has been reviewed from disassembly, through overhaul, to build and final test. At each stage, the processes and documentation have been reviewed to ensure that the necessary technical information is present. In cases where further information is

deemed necessary, technical specialists have been engaged to provide this information. As an example, David Brown were contracted to provide guidance on the Class 142 final drive casing tolerances, effectively being paid to release critical elements of their IPR [Intellectual Property Rights].

All available information will be made available to operators and maintainers through the update of the overhaul specification, CR/CI0590, timescales are as described above.

After reviewing the information received ORR wrote to Angel Trains, on 15 October 2012, asking it to confirm when it has completed its actions to address the recommendation.

25. **Angel Trains Ltd** in its response on 16 November 2012 advised that:

In collaboration with the industry (including other vehicle owners, train operators, component suppliers and technical specialists), Angel Trains is nearing completion of the revised overhaul instruction for the Class 142 SCG final drive, CR/CI0590. This revised specification has now been reviewed by the industry and Issue 2 finalised.

As referred to in relation to Recommendation 1 Angel Trains is progressing the Engineering Change for the specification and it is envisaged that this will be approved by end-2012, with implementation in Q1: 2013 through a Contract Variation Order.

Angel Trains continues to collaborate with other industry stakeholders through participation in on-going industry meetings aimed at addressing issues arising from the Durham inquiry.

ORR Decision

26. After reviewing information received from Angel Trains Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Angel Trains Ltd has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: Implemented

ORR Conclusion

The responses from Porterbrook Leasing Company Ltd and Angel Trains Ltd are consistent.

Most original drawings have been made available and the original equipment manufacturer (OEM) has assisted in producing a revised version of the Component Overhaul Instruction (COI), which reduces the risk of final drive failure.

ORR does not believe it is essential that these companies have all the original drawings; as they have a good understanding of component tolerances and the oil pump reliability.

ORR was also provided with:

- an updated copy of overhaul instruction CR/CI0590 CLASS 14X SCG FINAL DRIVE Issue: 2; and
- a copy of a 'close-out' report by ESR Technology: ESR/NCT/2013/3788/Issue 3 (Feb 2013)

ORR is satisfied with the actions taken to ensure that key design information is made available to companies undertaking work on class 14x final drives.

Recommendation 5

The objective of this recommendation is to ensure that the final drives are tested in conditions representative of their operational duty before being released to the operator.

The owners of class 14x vehicles should review the testing of the final drives after overhaul to confirm that it is done in conditions sufficiently representative of their operational duty and where appropriate amend the testing requirements accordingly. The following areas should be considered:

- operational speed;
- loading on the shafts; and
- external environmental conditions.

Details of steps taken or being taken to implement the recommendation

27. **Porterbrook Leasing Company Ltd** in its initial response on 17 September 2012 advised that:

As previously detailed, the overhaul of final drives is subject to a series of tests that aim to confirm the required standards of overhaul have been achieved. These tests include the measurement of bearing temperatures, oil temperature and oil pressures in both directions of rotation. This is coupled with vibration measurement and analysis to ensure the smooth operation of the gearbox.

In the revision to the overhaul specification, additional parameters will be defined that will ensure that the rate of rise of temperature complies with a statistical norm and that variations to this norm will require further investigation to identify the reasons for the variation.

Porterbrook do not intend to undertake these tests with a transmitted torque within the input shaft and final drive assembly, as tests are predominantly aimed at measuring the condition of the bearings. This is based upon Porterbrook's belief that a final drive assembly with a driveshaft that is perpendicular to the axle and in a horizontal plane does not impart loadings on the input shaft bearings.

Porterbrook does not believe that varying environmental conditions have a significant effect on the operation of the final drives built to the correct parameters. However, the revised testing will take into account the ambient temperature within the test environment and the results corrected for this ambient.

After reviewing the information received ORR wrote to Porterbrook, on 15 October 2012, asking for more detail on how it has considered the three bullet points in the recommendation as part of its review.

28. **Porterbrook** in its response on 15 November 2012 advised that:

In response to the requirement of the ORR for more detail relating to the three bullet points within the recommendation Porterbrook offer the following

- *Operational speed*

Porterbrook has reviewed the rotational test speed for the final drive and concluded that an increase in test speed to 2000 rpm is representative of operational conditions. This requirement has been implemented with the over-hauler and is included within the latest review CR/CI0590 (awaiting publication).

- *Loading on the shafts*

The loading on the shafts has been considered, and has been the subject of correspondence between Porterbrook and the RAIB.

Porterbrook reason that the load on the input shaft bearings, in a testing environment, is independent of transmitted torque and has concluded, along with Angel Trains, Northern Rail, ESR Technology and Interfleet Technology, that the loading the shafts is not necessary when testing a final drive following overhaul.

It should be noted that final drive original equipment manufacturers, when overhauling their own final drives to not undertake routine post overhaul testing with a load on the shafts.

- *External Environmental Conditions*

As part of the investigation into gearbox bearing failure and development of the revised overhaul procedure, Angel Trains contracted ESR Technology and its National Centre of Tribology to undertake a programme of work to investigate bearing reliability. This work included testing for change in bearing clearance due to temperature differentials between inner and outer races.

External temperature conditions of -15°C to +40°C were achieved and the associated bearing temperature differentials identified. The data from these tests was used to determine gearbox end float requirements such that the final drive will accommodate representative environmental conditions.

Porterbrook do not support routine testing for environmental conditions as it considers, based on the above, that the overhaul specification has been developed to accommodate representative environmental conditions.

ORR Decision

29. After reviewing information received from Porterbrook Leasing Company Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Porterbrook Leasing Company Ltd has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: *Implemented*

30. **Angel Trains Ltd** in its initial response on 14 September 2012 advised that:

Angel Trains consider that post-overhaul testing of the final drive principally serves two purposes: firstly to identify any issues with the overhaul / build of the drive and secondly to “bed in” the drive gears. It is unusual for Suppliers of final drives to do any more above this following a routine overhaul.

As part of final testing detailed in CR/CI0590, equipment shall be available to monitor oil pump pressure and bearing temperatures at five locations on the drive. Ambient temperature is also to be recorded. Temperatures are recorded every 30 seconds throughout the duration of the test (minimum of 3 hours) and stored in a suitable data logger.

The data collected during testing is monitored and any readings outside the defined range results in the test being stopped and the final drive investigated. The historic trends of the temperature rise with time from the data logger will give a good indication of the operating condition of the bearings and the gears within the final drive.

The Supplier is required to generate a graph of average temperature rise above ambient against time based upon a significant sample size of final drives tested. Comparing the results of each overhauled final drive against this average line, any drives that do not closely follow the temperature rise trend should be subjected to a detailed examination and retest until the temperature rise curve follows the normal trend line.

A copy of the test records from the data logger is placed with the final drive build records. This process is more comprehensive than the previous testing regime and should ensure that any issues are identified and rectified before the drive is released to operators.

Operational Speed

Angel Trains recognise that previous post-overhaul testing was not carried out over the full speed range that the drive would see in service. In light of this, Angel Trains’ Supplier for the overhaul of the final drives now tests post-overhaul up to a speed of 2000 rpm, which is fully representative of operational conditions.

Loading on the shafts

Angel Trains consider that loading on the shafts would be more applicable to a Type Test and is, therefore, not required as part of a final overhaul test, the purpose of which is to identify any deficiencies with the overhaul / build process. Angel Trains have consulted with other industry Suppliers of new and overhauled final drives, the outcome being that loading on shafts is not usually included as part of the post-overhaul final test. The technical investigation work completed by ESR Technology considered all aspects of the final drive and its installation, including any influence of the cardan shaft on performance, and this work did not raise a recommendation to introduce loading on the shaft as part of the final testing. Therefore, Angel Trains consider that it is not necessary to introduce loading on the final drive shaft during the post-overhaul testing and no further action is currently proposed in respect to this.

External environmental conditions

Angel Trains considers that replicating the full range of external environmental conditions is over and above what is necessary as part of a routine post-overhaul final test. Angel Trains engaged ESR Technology to complete bench testing of the final drive where oil and housing temperatures of between -15°C and +40°C were achieved. The purpose of this testing was to identify the appropriate build tolerances of final drive, which are now included in the overhaul process and revised documentation. Therefore, Angel Trains consider that the final drive design has already been tested in conditions representative of the range to be encountered in operational duty.

ORR Decision

31. After reviewing information received from Angel Trains Ltd, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Angel Trains Ltd has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: *Implemented*

Recommendation 6

The objective of this recommendation is to ensure that Northern Rail's plans for dealing with accidents and incidents are adequate.

Northern Rail should complete the review of its procedures governing post-accident actions and implement any necessary changes to ensure that the risks to personnel and the environment from movement of damaged trains and trains with defective equipment is appropriately managed.

Details of steps taken or being taken to implement the recommendation

32. **Northern Rail** in its initial response on 6 September 2012 advised that:

Northern Rail has conducted a full review of this incident. It is acknowledged that actions taken by Northern staff did not include appropriate safeguards and checks to move the unit in a controlled manner. The review raised the following recommendations and noted actions which have been implemented:

1. The Head of Fleet Production shall brief all Maintenance Controllers on the outcome of this incident / investigation as a 'lessons learnt' exercise on communication and correct identification of defects and faults.

The Maintenance Controllers have each received a copy of the report and signed to say they have read and understand the content.

2. The Engineering Compliance Manager as part of the standard review and update of SMSP 4.01 Vehicle Incidents shall update the procedure to specifically call up assessing the risks and calling out engineering staff to attend incidents as necessary prior to any movements taking place.

The update of SMSP 4.01 is planned to be issued as part of the SMSP Update 30 cycle, the draft is to be issued for review by 10 October 2012.

3. The Engineering Training and Competence Manager shall update QMSP-06-003 Competence Assessment Maintenance Controllers as a minimum to include mandatory questions on dealing with major incidents / significantly degraded units (e.g. derailment, collision, door open in traffic, components adrift) and assessing the risks and the need to call out engineering staff.

A full review of the Maintenance Controllers Competence process was undertaken by the Engineering Training and Competence Manager, the Production Support Manager and a Maintenance Controller during June 2012. A number of actions came from that review which require a number changes to the competence procedures and processes, a timescale for the changes is still under development with the aim for the new procedures to be drafted by the end of September 2012

4. The Engineering Training and Competence Manager shall update QMSP-06-003 Competence Assessment Maintenance Controllers as a minimum to enhance the 'Observation Test' to ensure that correct details / nature of fault are identified and confirmed with the driver.

A full review of the Maintenance Controllers Competence process was undertaken by the Engineering Training and Competence Manager, the Production Support Manager and a Maintenance Controller during June 2012. A number of actions came from that review which require a number changes to the competence procedures and processes, a timescale for the changes is still under development with the aim for the new procedures to be drafted by the end of September 2012

5. The Head of Operational Safety and Head of Fleet Technical to prepare a brief outlining the risks from this type of incident and add to driver briefing and training.

An article has been placed in the Northern 'Cabs' magazine which is issued to all traincrew and reviewed during safety briefs. The article is also included as part of the new driver training programme. There has been high profile publicity and cascade briefing on the emerging issues related to final drives, particularly emphasising the role that traincrew can play in early identification of failures, such as reporting vibration or excessive noise from the drive train.

6. The Control Operations Manager to brief the Duty Control Managers (and deputies) on the importance of keeping accurate records, particularly during major incidents, within the Control Log to ensure decisions are accurately recorded.

The Control Operations Manager has issued a number of Control Briefs which are issued to ALL Controllers and clearly document Logging Standards. In addition to this the Duty Control Manager Safety Brief from March 2012 covered the full incident for briefing to the Duty Control Managers.

7. The Control Operations Manager and Head of Fleet Production to brief the Duty Control Managers (and deputies) and Maintenance Controllers on the importance of maintaining communication with each other throughout a major incident.

The Control Operations Manager sent an email (Production Support Manager Signature also on email) to all controllers specifying that the flow of information between Duty Control Managers (and deputies) and Maintenance Controllers is to be complete to ensure that all parties have a full understanding of a situation.

It is notable that when 142003 failed at Plawsworth in April 2012, this incident was handled correctly by the Control and Engineering staff involved. The unit was

recovered using a another train, as neither engine could be started, and was moved to Heaton at 25mph with technical staff accompanying it, after a rotation check had been carried out on site to confirm all was well to move the train.

33. After reviewing the information received ORR wrote to Northern Rail, on 7 February 2013, asking it to advise if its actions to address the recommendation had been completed.

34. Northern Rail in its response on 14 March 2013 advised that:

SMSP 4.01 was delayed due to the review of the rule book being undertaken for defective on train equipment: As this has been delayed again under consultation till December [2012] we will include the attached in next SMSP round for approvals in April [2013].

There are a couple of sections that may be expanded following completion of the rule book consultation, but we believe the procedure to be 99% complete, and it addressed the issues identified in the recommendation.

35. Northern Rail provided ORR with a copy of the draft procedure.

The Maintenance Controller Competence Management System procedure (now moved from the engineering QMS to the safety management system) update was not completes in the timescales originally indicated, but it is in place now.

36. Northern Rail provided ORR with a copy of the recently implemented procedure.

37. On 1 May 2013 Northern Rail advised that:

As planned, the procedure [SMSP 4.01] was finalised for consultation in the current (April 2013) round of safety procedure updates, this (and other procedures) are currently going through consultation with staff groups and will be implemented at the end of the month [May 2013].

38. On 8 June 2013 Northern Rail advised that:

Consultation was completed on the revised SMSP 4-01 as planned and implementation is proceeding for formal implementation from 28th June.

ORR Decision

39. After reviewing information received from Northern Rail, ORR has concluded that, in accordance with the Railways (Accident Investigation and Reporting) Regulations 2005, Northern Rail has:

- taken the recommendation into consideration; and
- has taken action to implement it.

ORR will write to RAIB if it becomes aware that the information above is inaccurate.

Status: *Implemented*