



Rail Accident Investigation Branch

Rail Accident Report



**Incident at Greenhill Upper Junction, near
Falkirk
22 March 2009**

Department for
Transport

Report 04/2010
March 2010

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

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Incident at Greenhill Upper Junction, near Falkirk, 22 March 2009

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Preface

- 1 The sole purpose of a Rail Accident Investigation Branch (RAIB) investigation is to prevent future accidents and incidents and improve railway safety.
- 2 The RAIB does not establish blame, liability or carry out prosecutions.

Key Definitions

- 3 The report contains abbreviations and technical terms (shown in *italics* the first time they appear in the report). These are explained in appendices A and B.

Summary of the Report

Key facts about the incident

- 4 The incident occurred on 22 March 2009 when the 09:17 hrs passenger train from Alloa to Glasgow Queen Street traversed Greenhill Upper Junction (figure 1), where the line from Larbert and Stirling joins the Edinburgh and Glasgow line. One of the trailing *point ends*, which were part of a set of *switch diamonds*, was in the incorrect position and as the train *trailed through* them, it forced the *switch blades* to the correct position causing damage to the mechanism.
- 5 The train was not derailed and continued normally to its destination. There were no injuries caused to either train crew or passengers, and there was no damage to the train.
- 6 The incident followed overnight work to renew a *point machine* at Greenhill Upper Junction. As part of this work, the point machine controlling the point end that was trailed through was switched to *manual operation*. On completion of the work, this point end was not restored to power and the signaller was able to set a route across the switch diamonds for the Glasgow train despite the fact they were in the incorrect position.
- 7 The subsequent investigation by Network Rail immediately after the incident found that additional wiring had been incorrectly installed in the point machine fitted to the other end of the switch diamonds and which had been fitted on site on the night of 17/18 January 2009. The additional wiring affected the working of the *detection contacts* within the point ends that were trailed through resulting in a *wrongside signalling failure*.
- 8 The fault remained undiscovered between 18 January 2009 and the time when the incident occurred.

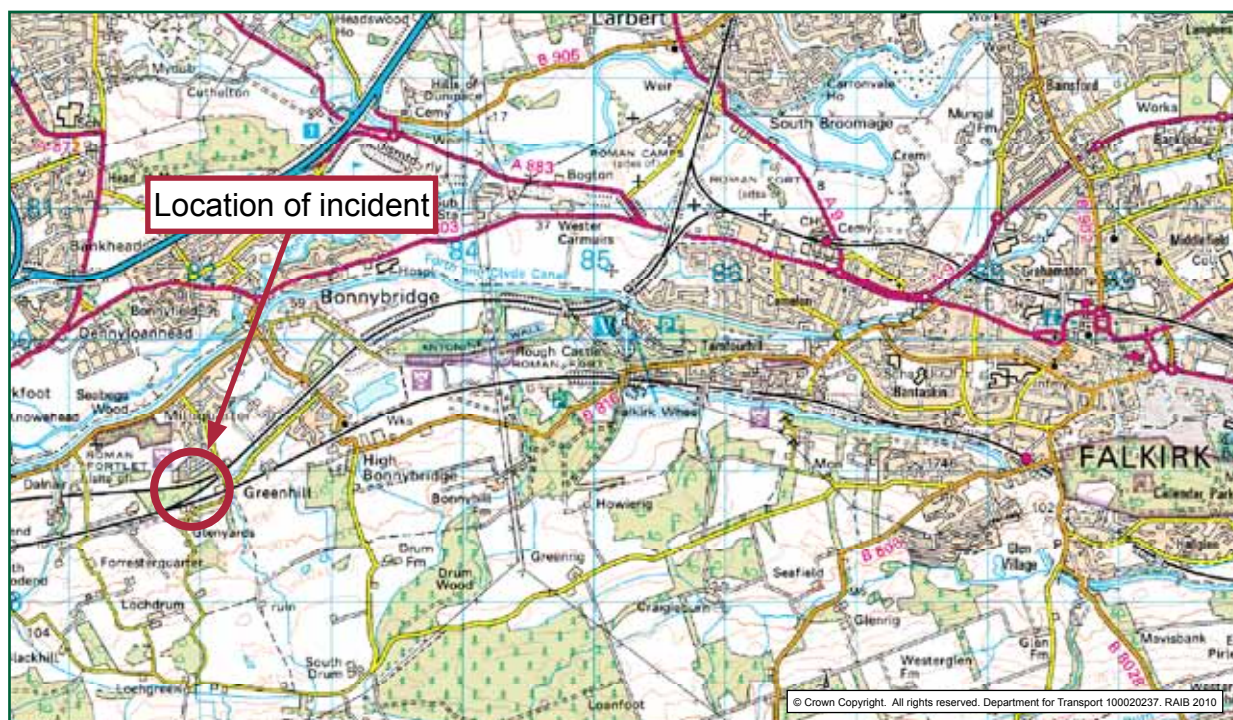


Figure 1: Extract from Ordnance Survey map showing location of incident

Immediate cause, causal and contributory factors, underlying causes

Immediate cause

- 9 The immediate cause of the incident on the 22 March 2009 was that 125 *points* were detected in the reverse position by the signalling system with 125C point ends in the normal position. This allowed the protecting signal to *clear* to a proceed aspect for train 2N50 which subsequently trailed through 125C point ends.

Causal factors

- 10 Causal factors were:
- a. Extra wiring was incorrectly installed in the point machine for 125B point ends at Lionverge's Falkirk depot. This point machine was installed on site at Greenhill Upper Junction on 17/18 January 2009.
 - b. The extra wiring was not detected before 125B point machine was installed on site at Greenhill Upper Junction on 17/18 January 2009 because there was no formal procedure in place at the Falkirk depot to carry out any checks or tests.
 - c. The site testing carried out at Greenhill Upper Junction on 18 January 2009 was not carried out correctly because:
 - the tester did not carry out a wire count of the point machine fitted to 125B point ends; and
 - the tester did not correctly observe the state of the detection relay positions during the *out of correspondence* testing.
 - d. The indications on the signaller's *NX panel* were not correctly responded to during the out of correspondence testing.
 - e. 125C point ends were not switched back onto powered operation on 22 March 2009.
- 11 The following factor was considered to be probably causal:
- a. The installation of the wiring to the point machines for 125B and 125C point ends was carried out to a single wiring diagram that showed both machines on it.

Contributory factors

- 12 The following factor was contributory:
- a. The tester was not appointed until the start of the shift on 17/18 January 2009.
- 13 The following factors were considered to be possibly contributory:
- a. It was dark and the weather conditions during the testing were poor: there was a brief snow shower just when the point detection and correspondence testing was being carried out and it was cold.
 - b. The testing was carried out at a time of day when the tester would probably have been tired because of the length of time he had been awake since sleeping during the night of 16/17 January 2009. It was also a time of day when levels of alertness are at their lowest.

Underlying causes

- 14 The underlying causes were:
- a. The Signalling Maintenance Testing Handbook (SMTH) not requiring documentation of stages of testing; only the completion of a complete test plan such as NR/SMTH/Part 4/PC01.
 - b. The lack of separate drawings for each point machine wired at Falkirk depot.
 - c. The lack of planning of the organisation of the testing.
 - d. Network Rail not expressing a preference in its process documents that pre-testing is carried out prior to site installation as far as possible.

Additional observations

- 15 The following observations are made:
- a. The out of correspondence test in the SMTH does not specify whether or not the panel indications should be monitored as part of the test. This is also not fully covered in training courses.
 - b. The railway industry does not have a clear view about how the detection test should be carried out in the case of HW type point machines.
 - c. There is a misconception amongst staff about how the detection relays should be observed during the manual operation of points during the out of correspondence test.
 - d. Annotated copies of maintenance drawings at Greenhill had not been updated and there was said to be a backlog generally in updating drawings.

Recommendations

- 16 Recommendations can be found in paragraph 211. They relate to the following areas:
- The carrying out and testing of pre-site work where project type work is carried out under the maintenance testing arrangements.
 - Planning in advance the testing of completed or partially completed project type work carried out under the maintenance testing arrangements.
 - The correct and intended method of points testing.
 - The creation of a new process suitable for small scale project work that fits between the arrangements required by works testing and those by maintenance testing.
 - The documentation of specific stages of testing.
 - Updating maintenance drawings following alterations made.

The Incident

Summary of the incident

- 17 At about 09:45 hrs on 22 March 2009, train 2N50, the 09:17 hrs from Alloa to Glasgow Queen Street, formed by a three-car class 170 *diesel multiple unit*, traversed Greenhill Upper Junction (figure 2) at 64 mph (103 km/h). One of the point ends, designated 125C, forming part of a set of switch diamonds, was in the incorrect position and the train trailed through them forcing them across to the correct position and damaging the mechanism as a result.

The parties involved

- 18 The infrastructure at Greenhill Upper Junction is owned and operated by Network Rail and the train involved was operated by First ScotRail. The incident followed work that had been undertaken by Lionverge (Civils) Ltd, a contractor to Network Rail, and henceforward referred to as Lionverge. All these parties freely co-operated with the investigation.
- 19 Lionverge was founded about 25 years ago, specialising in small scale railway civil engineering work. Following railway privatisation, the company diversified into railway signalling work and, with an increasing workload generally, set up several depots away from its main Northampton base. One of these was at Falkirk to facilitate signal engineering work in Scotland.
- 20 Following structural changes in the railway industry, such as Network Rail carrying out more of its work 'in house', Lionverge saw a decline in its workload and closed all its outbased depots apart from the one at Falkirk. Subsequently, just after the incident at Greenhill Upper Junction occurred, Lionverge also closed its depot in Falkirk and made its staff there redundant.
- 21 There was no connection between the incident at Greenhill Upper Junction and the closure of Falkirk depot, which was planned before the incident occurred.

Location

- 22 Greenhill Upper Junction is 17 miles 29 chains (28 km) from Glasgow Queen Street station on the main line between there and Edinburgh Waverley station. It is about 3 miles (5 km) west of Falkirk and is where the line from Larbert and Stirling joins the Edinburgh and Glasgow line (figure 2).
- 23 The permissible speed for trains crossing the junction to or from the Larbert direction is 70 mph (113 km/h); the permissible speed for trains on the Edinburgh and Glasgow line is 100 mph (161 km/h).
- 24 Trains crossing the junction from the Larbert direction must first pass over the switch diamonds consisting of 125C and 125B point ends on the up Edinburgh and Glasgow line, followed by the trailing point ends of 125A turnout, located where the line from Larbert joins the down Edinburgh and Glasgow line.

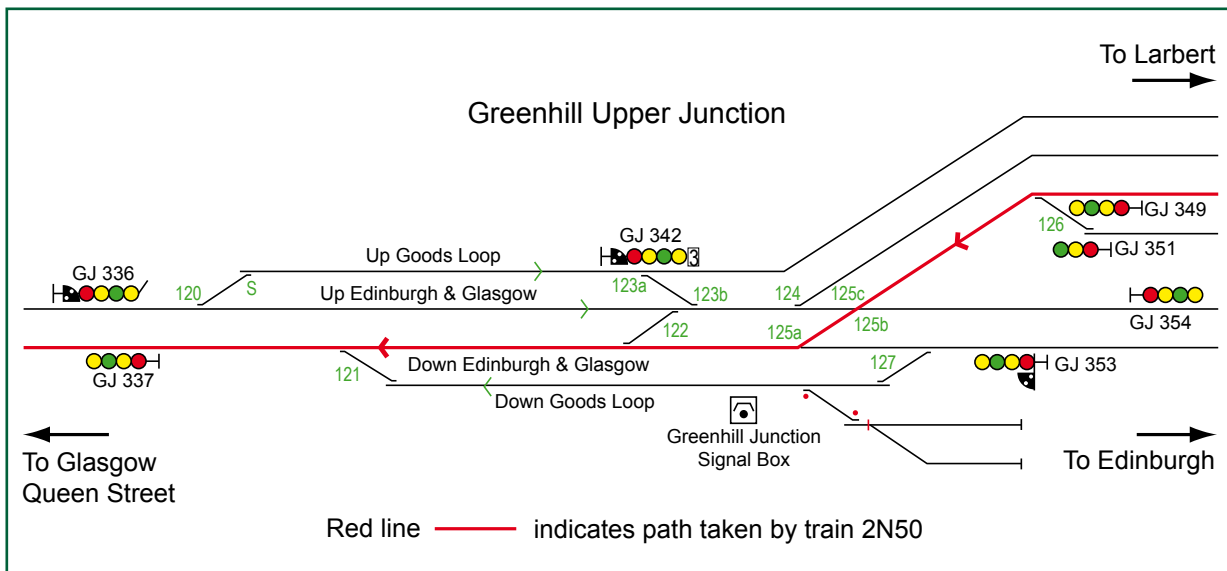


Figure 2: Track and signalling layout at Greenhill Upper Junction

Signalling equipment

- 25 The signalling at Greenhill Upper Junction is controlled from Greenhill Junction signal box. This is located locally at Greenhill Upper Junction and is in the same building as the *interlocking*. The interlocking is of the GEC *geographical route relay interlocking* type dating from the early 1970s, and the signaller's interface is a small NX panel (figure 3). The signaller sets routes by pressing entrance and exit buttons on the panel, which – providing the required conditions in the interlocking are met – causes points to move to the correct positions and the appropriate signals to clear. The signaller can also operate the points during out-of-course working by using *individual point switches* located in a row along the top of the panel.
- 26 The method of operation is *track circuit block* using *track circuits* to detect the absence of trains and with *multiple aspect colour light signals*.

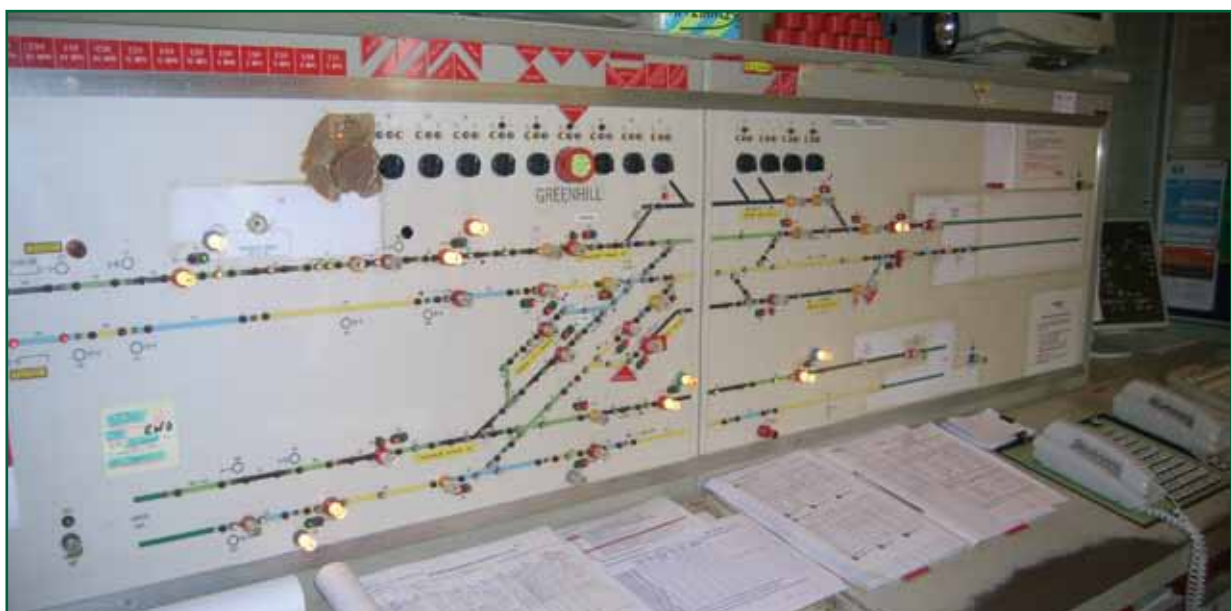


Figure 3: Greenhill Junction signal box signaller's panel

The Incident

- 27 The incident occurred following work by a team of four Lionverge staff who renewed 125B point machine at Greenhill Upper Junction during the night of 17/18 January 2009. Although testing was carried out afterwards, errors were made and some additional wiring within the point machine was not discovered. This wiring effectively bypassed the detection contacts in 125C point machine, the safety of operation of which was then reliant on the correct operation of the point motor in response to commands from the interlocking. The actual position of the *switch rails* in either the *normal* or *reverse positions* was no longer checked by the signalling system, although loss of detection was still correctly sensed by it. The fault condition existed when the point ends were detected in either the normal or reverse positions, but not when the blades were in an intermediate position.
- 28 The fault did not reveal itself until 125C point machine was inadvertently left on manual operation, with 125 points in the normal position, following work by Lionverge staff during the night of 21/22 March 2009 to renew 126A point machine. In order to transport the new point machine on a rail mounted trolley to where it was needed, Lionverge staff had manually operated 125C point ends to the reverse position by winding a crank handle.
- 29 When the crank handle is inserted, a switch is operated which breaks the feed to the motor circuit to ensure that the motor cannot operate when the crank handle is in use. On completion of the work, the point ends were manually operated back to normal using the crank handle, which was then removed. However, removing the crank handle does not alone remake the electrical switch in the motor circuit - a latch has to be operated by hand before the motor feed circuit is restored. This was not done, so the point ends were left with the motor in an unpowered state.
- 30 The first trains, following the completion of work on 21/22 March 2009, were along the Edinburgh and Glasgow main line requiring 125 points to be in the normal position. The failure to switch 125C point machine back onto power was therefore not apparent. However, when the Greenhill signaller set a route requiring all 125 points ends to be in the reverse position, 125C point ends remained in the normal position. The wiring fault in 125B point machine resulted in the signalling system not detecting that 125C point ends had remained in the normal position and the interlocking enabled the *protecting signal* GJ349 to clear (figure 2).
- 31 Train 2N50 trailed through 125C point ends at 64 mph (103 km/h) causing damage to them. This became apparent to the signaller because he received an '*out of correspondence*' indication on the panel indicating that 125 points had lost detection. Figure 4, taken from the train's forward facing CCTV equipment, shows the position of the switch diamonds as the train approached them.

Consequences of the incident

- 32 The actual consequences of the incident were limited to the damage caused to the mechanism of 125C point ends. However, if these point ends had not been manually operated back to the normal position, but had been left in the reverse position instead, a train travelling on the up Edinburgh and Glasgow line towards Edinburgh would have encountered the wrongly set point ends in the *facing direction* at 100 mph (160 km/h). The outcome then would almost certainly have been a derailment at high speed.



Figure 4: Forward view of Greenhill Upper Junction as train 2N50 approached showing the position of 125C point ends (normal) and 125B point ends (reverse)

Events following the incident

- 33 The signaller reported the fault to the local Network Rail signalling maintenance organisation, which sent staff to site to investigate. Later on 22 March, Network Rail staff found the additional wiring (two additional wiring straps) fitted to 125B point machine. The wiring straps were removed, the damage to 125C point ends repaired, and a full test was carried out. 125 points were signed back into operational use at 00:40 hrs on 23 March 2009.
- 34 Network Rail checked the integrity of all the other point machines that had been installed by Lionverge, but did not find any further defects.
- 35 Owing to an initial report that the train could have derailed and then rerailed itself when trailing through 125C point ends, it was examined by First ScotRail staff. However, no evidence of any derailment was found either on the train or on the track.

The Investigation

Investigation process and sources of evidence

36 The sources of evidence used during the investigation were:

- statements of witnesses;
- information obtained from the signalling system data logger in the relay room at Greenhill;
- information obtained from the on train data recorder of train 2N50;
- film images from the forward facing CCTV camera fitted to the front of train 2N50;
- photographs obtained from Network Rail;
- maintenance records;
- circuit diagrams in Greenhill Junction relay room;
- documents and correspondence associated with the planning and undertaking of the work; and
- standards covering maintenance and testing of signalling equipment.

Key Information

The circuitry associated with 125 points

- 37 A detailed description of the circuitry associated with the operation and detection of 125 points is in appendix F.

Applicable standards and testing processes

Railway Group Standards

- 38 *Railway Group Standard* GK/RT0209 'Testing and commissioning of signalling and operational telecommunications systems' defines the scope of *works testing* and the scope of *maintenance testing*.
- 39 Works testing is used for new work that is defined in GK/RT0209 as 'work that changes, or potentially changes, the configuration or functionality of the system. The work is carried out in accordance with engineering details supplied for the purpose'. It includes the installation of totally new systems, the alteration of existing systems, and the abolition of existing systems. The requirements of works testing include:
- the appointment of a named person to be in overall charge of the testing;
 - independence between those testing and those who designed and installed the work;
 - documentation of the testing and commissioning process;
 - risk assessment and mitigation relating to the testing activity;
 - the preparation of a testing strategy;
 - the production of a documented test plan;
 - documentation of the test specifications required;
 - a system of test recording and certification;
 - a process to ensure that only current documents are used;
 - a method of recording errors identified during testing; and
 - a method of dealing with outstanding actions.
- 40 GK/RT0209 specifies that testing should be undertaken in phases and that this may include off-site testing under the control of the test plan.

- 41 The scope of maintenance testing in GK/RT0209 covers work that is like-for-like and does not require any form of *validation*. It defines like-for-like replacement as ‘the removal and restoration of an item of equipment in a previously working and commissioned system, where the work does not change the configuration or functionality of the system’. Engineering details are not provided for the work, and instead the existing infrastructure records such as maintenance copies of drawings are used as the reference documents. This includes replacing an original piece of equipment with a new item that operates to produce the same result. It does not apply where extensive and simultaneous like-for-like replacement or reinstatement is planned, in which case the standard requires works testing. It requires that one person is placed in charge of the testing who should independently verify that the installation work is carried out according to the drawings. Where the work can be pre-planned, there should be a documented test plan produced which should be verified by a competent person. The testing must ensure that:
- a like-for-like replacement is properly installed;
 - affected products conform to the as-built design, product specifications and relevant standards; and
 - affected systems operate correctly.

Network Rail company standards

- 42 The requirements in GK/RT0209 are translated in Network Rail into company standards NR/SP/SIG/11231 ‘Signalling Maintenance Testing Handbook’ (SMTH) and NR/SP/SIG/11221 ‘Signalling Works Testing Handbook’ (SWTH). SMTH contains a suite of standard maintenance test plans obviating the need under maintenance testing to produce a documented test plan.
- 43 Maintenance testing is based on the assumption that equipment is correctly wired and documented before work starts. Its requirements include:
- a maintenance tester shall be in overall charge of the testing and be independent of the installer;
 - appropriate maintenance test plans contained within the SMTH shall be selected;
 - the part of the signalling system affected by the work shall be checked for correct operation, eg observing that points move in correspondence with the signaller’s controls;
 - a record of test shall be produced when all the work and the testing is completed;
 - maintenance testers shall be competent and hold an appropriate licence issued by the Institution of Railway Signal Engineers; and
 - the installation shall be checked against the diagrams before work is started and again after work is complete to check that the installation is correct.
- 44 Following an incident at Derby on 17 September 2005, Network Rail issued a ‘Notice Board’ instruction in December 2007 to clarify the difference between testing to the SMTH and testing to the SWTH. The instruction emphasises that the SMTH is restricted in applicability, and it is only very occasionally a suitable process for small scale enhancements with specially written test plans.

- 45 The SMTH permits the renewal of obsolete equipment and its replacement by the current operationally equivalent type, providing that the electrical integrity of the circuitry and interlocking remains unchanged. The work under the SMTH must be based directly on an existing proven design and must not introduce new design features to a system.
- 46 The SMTH specifically permits the renewal of point machines from one type to another, where no change to the wiring arrangement outside the machine is required. The SMTH specifies that maintenance test plan PC01 'Replace a complete point machine' be used and that testing shall include a *wire count* and a point detection and correspondence test (explained later in paragraphs 52 to 61).
- 47 The SMTH also permits the installation of a *disconnection box* which requires elements of maintenance test plan CA04 'Joint/add a length of cable/line wire' to be used. The precise elements of CA04 are not specified further, apart from a requirement to carry out a point detection and correspondence test in those cases where an affected cable goes to a point detector. CA04 does not require a wire count of the disconnection box, or other parts of the circuit, to be carried out.
- 48 The SMTH also contains maintenance test plan CA03 'Renew a cable/wire'. This requires a wire count to be carried out both before and after the installation of a new cable/wire.
- 49 Under the SMTH, minor alterations can be undertaken from site maintenance prints and annotated in red for new work. The tester must sign and date test copies of the drawings.
- 50 The SMTH does not specify where the work should be undertaken and does not mention whether it is permitted to carry out some of the testing off-site before site installation.

Replacing a point machine

- 51 Maintenance test plan PC01 consists of a list of numbered steps in a logical sequence divided into two sections: 'before installation work' and 'after installation work'. It includes the following:

Before installation work

- check replacement unit (point machine) is not damaged and is of correct type;
- wire count existing unit to the wiring diagram;
- check existing wiring has safe insulation; and
- check existing wiring is correctly labelled.

After installation work

- check replacement unit is correctly installed;
- check that wiring replaced is labelled;
- wire count the replacement unit to the wiring diagram; and
- point detection and correspondence test the affected point ends.

Point detection and correspondence testing

- 52 SMTH Test B8 'Point detection and correspondence test' consists of the following (and carried out in this order):
- point position check – to ensure a correct understanding of the lie of the point ends in their normal and reverse positions;
 - correspondence test – to ensure that the signal box controlling device, controls and indications correspond with the lie of the point ends for both normal and reverse positions;
 - detection test – to ensure that all the contacts are in the circuit and effective; and
 - out of correspondence test – to ensure that detection cannot be obtained if one or more point ends are not in the correct position.
- 53 The point end that has had its equipment changed is referred to in the test as the 'affected end'.
- 54 All the tests must be carried out to all point ends with a common detection circuit, which includes the affected end. At Greenhill Upper Junction therefore, following the fitment of 125B point machine, 125A, 125B and 125C point ends all required testing.

Correspondence test

- 55 This test requires the points to be operated to the normal and reverse positions in turn with a check that the control and detection relays, the position of the signaller's control device, and the signaller's indications, all correspond with the lie of the points.

Detection test

- 56 This test requires, for all ends of the set of points, that each detection contact is broken three times in succession with a check being made that the correct local detection relay de-energises each time for both normal and reverse positions.

Out of correspondence test

- 57 This test contains the following steps:
1. Normalise all the point ends. Refer to the first step of the permutation chart (see table 1 for an example permutation chart that covers three point ends).
 2. Isolate (only) the point ends indicated by a zero (0) on the permutation chart. The point ends indicated by a figure one (1) should be left so that they can be operated on power by the signaller.
 3. Ask the signaller to operate the points to the reverse position. Check they indicate out of correspondence.
 4. Manually operate the isolated point end(s) to the reverse position. Check that reverse detection is only given at the full reverse position.
 5. Leave the isolated ends isolated. Ask the signaller to operate the points to the normal position. Check they indicate out of correspondence.
 6. Manually operate the isolated end(s) to the normal position. Check that normal detection is only given at the full normal position.

7. Repeat steps 2 to 6 following the next step on the permutation chart until all permutations are complete.
 8. Reconnect the isolated point drive(s).
- 58 The SMTH states that point detection in steps 4 and 6 above must be checked at the detection relay rather than by the indication in the signal box. It does not state for steps 3 and 5 how the check for out of correspondence is to be carried out, ie whether this should be of the detection relay alone, or of the detection relay and the indication on the signaller's panel.
- 59 During testing, point ends are manually operated by inserting a handle into one end of the machine and winding it to move the switch rails to the other position.
- 60 The 'full reverse position' and 'full normal position' referred to in the out of correspondence test are when the point ends have fully moved across to the new position and are locked in that position by the *facing point lock*. This requires the person manually operating the points to wind them until the facing point lock has engaged. Only then should the appropriate detection relay energise.
- 61 It is optional whether or not the tester records the completion of the different stages of the test. The SMTH states that the permutation chart grids are suitable for this purpose. The right-hand column is provided for the tester to tick on the completion of each permutation, but he is not required by the SMTH to use it for this purpose (table 1).

	End	End	End	
No.	1	2	3	Tick
1	0	0	0	
2	0	0	1	
3	0	1	0	
4	0	1	1	
5	1	0	0	
6	1	0	1	
7	1	1	0	

Table 1: permutation chart grid for three point ends
(0 denotes point end isolated)

Signalling circuitry design

- 62 Network Rail company standard NR/GN/SIG/11600 'Signalling and operational telecommunications design: technical guidance' requires that for new work involving point detection circuits, each point end should have its own pair of detection relays and the wires out to each detection contact in a point machine should be in a separate cable to the wires back to the *location case* or other equipment room containing the point detection relays. This is to avoid the possibility of the detection relays being falsely fed in the event of a failure of insulation inside the cable.
- 63 Under NR/GN/SIG/11600 therefore, each detection relay is required to be fed and returned by its own pair of wires, each of which runs in a separate cable. This is known as four wire detection and is the standard to which all new signalling work should be installed.

- 64 The detection circuit, including the 125 point detection relays, was a two wire detection circuit (appendix F, paragraph 9) with a single pair of detection relays common to all three point ends. This met the standard that applied when the signalling system at Greenhill was installed in the early 1970s, ie the wires of the point detection circuit shared the same cable.

Signalling installation

- 65 Network Rail company standard NR/GN/SIG/11210 'Signalling installation', in appendix 1D15, covers the standards applicable to wiring and terminations. It requires that wires are labelled and that during the process of installation, wires should be ticked on the drawing when they have been run, and the termination point should be circled on the drawing when the termination has been made. Appendix 2P05 of the standard includes the installation of disconnection boxes and appendix 2S10 covers the installation of electric point machines.

Competence requirements

- 66 The competence standards for staff undertaking work on signalling equipment on Network Rail are in Network Rail company standard NR/SP/CTM/012 'Competence and training in signal engineering'. One of the elements contains the standards that must be met to be able to 'conduct specified testing of electro-mechanical point machines, analyse and interpret the results'. This includes point detection and correspondence testing.
- 67 Network Rail does not specify the content of training courses and it is up to training providers to design their courses to deliver the training material needed to enable trainees to pass the assessments set by Network Rail related to the applicable competence standards.
- 68 Network Rail company standard NR/SP/SIG/10160 'Signal engineering: licensing scheme – confirmation of competence' mandates that staff who work on signalling equipment on Network Rail's infrastructure should be licensed by the Institution of Railway Signal Engineers (IRSE). The appropriate IRSE licence category for a person carrying out maintenance testing is 'maintenance tester'. Network Rail's NR/SP/SIG/10160 states that where staff have an SMTH certificate, they are deemed to be competent in the activity.

The planning of the work

The scope of the work

- 69 Network Rail decided to renew HW1000 point machines on the Edinburgh and Glasgow line by fitting the newer HW2000 type. This was to be carried out in anticipation of overhead alternating current electrification of the railway, and to achieve higher reliability.
- 70 The scope of the work was described in an engineering project specification issued by Network Rail on 8 June 2007 and was to cover the following:
- the replacement of 25 HW1000 type point machines with the newer HW2000 type (figure 5), which are immune to the effects of *alternating traction current*;
 - the fitment of *high stability sole plates* and mechanical *back drives* where required; and
 - the provision of plug coupled *tail cables* and disconnection boxes.



Figure 5: An HW2000 type point machine

- 71 The engineering project specification stated that the work was to be carried out and tested under maintenance testing procedures contained in Network Rail's Signalling Maintenance Testing Handbook. This was before Network Rail issued the Notice Board instruction that drew attention to the difference between testing to the SMTH and testing to the SWTH (paragraph 44).
- 72 Lionverge successfully tendered for the work which Network Rail subsequently split into two phases to be carried out over two financial years: 2007 to 2008 and 2008 to 2009. The contract for phase 1 was awarded on 26 September 2007 and covered nine point ends.
- 73 The engineering project specification stated that where the existing detection circuit was two wire (as at Greenhill), this would be converted to a four wire detection circuit (paragraph 63) using the two tail cables that connect to each point machine. One of these contained ten wires (cores) and the other four cores.
- 74 The engineering project specification required the contractor to produce a method statement using guidance from the SMTH. Network Rail's design office was also to provide a standard drawing, based on the guidance given in NR/GN/SIG/11600, showing a four wire detection circuit and plug couplers to enable the tail cables to be easily disconnected and reconnected to the point machine when required (eg when changing a machine).
- 75 Network Rail sent design drawings to Lionverge on two separate occasions showing how the wiring alterations were to be achieved. These followed the normal convention of showing new work in red and old work to be removed in green. Network Rail could not provide the RAIB with copies of these drawings.

- 76 Lionverge rejected these drawings because, according to witness evidence and correspondence obtained by the RAIB, it was concerned that the work could not be done under maintenance testing procedures and should instead be done under the more onerous processes covered by the Signalling Works Testing Handbook. Lionverge argued that the works were neither 'non-conceptual' nor 'like-for-like'. Network Rail accepted this, but to avoid the additional expense of using works testing procedures, it altered the scope so that maintenance testing procedures could still be used. The change in scope made the work completely like-for-like with the machine being renewed with one that was of modern equivalent type.
- 77 In the planning of the work, Network Rail's Scotland Territory had wished to update the existing detection circuitry so that it would be a four wire circuit (paragraph 62) and the connections to the point machines would be by plug couplers. This would have required wiring alterations in the location case where the detection relays were installed, and wiring loops to be fitted in the disconnection box. From witness evidence and correspondence obtained by the RAIB, Network Rail sought to avoid making wiring alterations in the location case by retaining the two wire circuit between the detection relays and the disconnection box and installing a four wire circuit to the point machines with wiring loops in the disconnection boxes to connect the circuits together.
- 78 The scope finally changed to:
- the detection circuit wiring to be like-for-like with the two wire detection circuit retained throughout (appendix F);
 - wiring of the tail cables directly to the machines, rather than by means of plug couplers;
 - any necessary wiring alterations to be carried out inside the machine;
 - a disconnection box to be provided as a break point in the tail cables, but not to contain any wiring alterations within it; and
 - the site diagrams in the location case and *relay room* to be amended manually to reflect the inclusion of the disconnection box for each machine with Network Rail being responsible for updating and re-issuing the source diagrams.

Method statements

- 79 For the phase 1 works, Lionverge wrote, and Network Rail accepted, a method statement dated 9 January 2008, before the scope of the project was finally clarified. Once the scope had been finalised, Lionverge produced an undated addendum to the method statement. The method statement itself was not updated afterwards to incorporate the addendum.
- 80 The phase 1 works were subsequently completed without incident with 125A point machine at Greenhill Upper Junction being renewed as part of this phase during the night of 2/3 February 2008.
- 81 The contract for phase 2 was awarded on 18 August 2008, to include seven point ends at Greenhill and nine at Cadder and Gartshore.

- 82 For the phase 1 works, Lionverge had been directly responsible for all aspects of the works. For the phase 2 work, Network Rail decided that it would undertake the responsibility for planning and implementing the required track *possessions* and for providing any staff required to do the permanent way work associated with the point machine replacement.
- 83 The method statement for the phase 2 works, dated 10 January 2009, followed the same format as the previous one for the phase 1 works, but it was changed to reflect the fact that Lionverge was no longer responsible for fitting the high stability soleplates, or organising the possession, as it had been for phase 1.
- 84 Neither method statement made any reference to any pre-site work being carried out at Lionverge's Falkirk depot, or how the testing would be organised for each specific point machine that was required to be changed as part of the project. Each method statement did contain the requirement that all the works would be tested according to SMTH procedures.
- 85 The installation of the disconnection box was to be in accordance with appendix 2P05 of Network Rail standard NR/GN/SIG/11210 (paragraph 65) and tested in accordance with maintenance test plan CA04 (paragraph 47).
- 86 Evidence was given that Lionverge planned the work on the basis that all the testing required by the SMTH would be carried out during site installation and it was not intended that any should be carried out at Falkirk depot. If Lionverge's process had included testing at Falkirk, this would have required a tester to carry out the testing and the generation of a written record confirming what had been done. Lionverge felt that partial testing in advance could have caused confusion and preferred instead that all the testing should be done on site.
- 87 Prior to each site installation, Lionverge made up a work pack which included a site specific task briefing sheet containing brief details of the work required, identified risks and mitigations, and required competences and PPE. Staff undertaking the work were required to sign that they had been briefed on the contents of the task briefing sheet.
- 88 The work pack also included a maintenance test plan listing the details of the work and the appropriate SMTH maintenance test plan number. Persons doing the work and carrying out the testing were required to sign this sheet. In relation to the work carried out on 17/18 January 2009 to renew 125B point machine, the work required was listed as:
- replace HW1000 point machine with HW2000, maintenance test plan PC01 (paragraph 46);
 - install disconnection box, maintenance test plan CA04 (paragraph 47); and
 - install four core and ten core cables from disconnection box to point machine, maintenance test plan CA03 (paragraph 48).
- The individual maintenance test plans were not broken down further, either into the discrete areas of work required to be carried out, or more specifically into the individual work items required by each test plan.
- 89 The records show that the staff who carried out the work at Greenhill on 17/18 January 2009 signed to confirm that they had been briefed and also signed against the relevant maintenance test plan list entries confirming the work they had carried out.

Pre-work carried out at Lionverge's Falkirk depot

- 90 Before the work, new (or reconditioned) HW2000 point machines were delivered to Lionverge's depot in Falkirk. Here, they were pre-wired prior to being installed on site. The drawings used for this purpose were digital prints of the maintenance copies kept in Greenhill relay room and marked up by Lionverge with what was required. This included the required length of the tail cables and the required wiring connections, which were marked on the drawing with a highlighter pen.
- 91 During the installation work, the individual wires were crossed through on the drawings by the installer, denoting that they had been connected. The tail cables were also required to be labelled with the identity of the point machine they were connected to, but there was evidence that this was not always done: after it had been installed on site the tail cables fitted to 125C point machine were found not to have been labelled.
- 92 Several employees who carried out work at Falkirk gave evidence that the installation work carried out there was checked by their colleagues, including wire counting. However, these checks were not part of any formal system and no records were maintained of any such checks being carried out. There are also no records of when specific point machines were pre-wired at Falkirk or who carried out the installation work. Evidence was given that the point machines for 125B and 125C point ends, and a third point machine, were in the depot together for pre-wiring very early in 2009 (Lionverge fitted 125C point machine at Greenhill Upper Junction during the night of 10/11 January 2009).
- 93 A single drawing (appendix D) showing the wiring for both 125B and 125C point machines was used to wire up the tail cables and fit additional wiring that was required in 125C point machine. 125C point machine was wired correctly, but 125B point machine was incorrectly wired the same as 125C. This resulted in additional wiring being installed in 125B point machine (figure 6).
- 94 Exactly when the error in wiring 125B point machine was made could not be positively identified owing to the lack of written records and the lack of recollection by those involved.

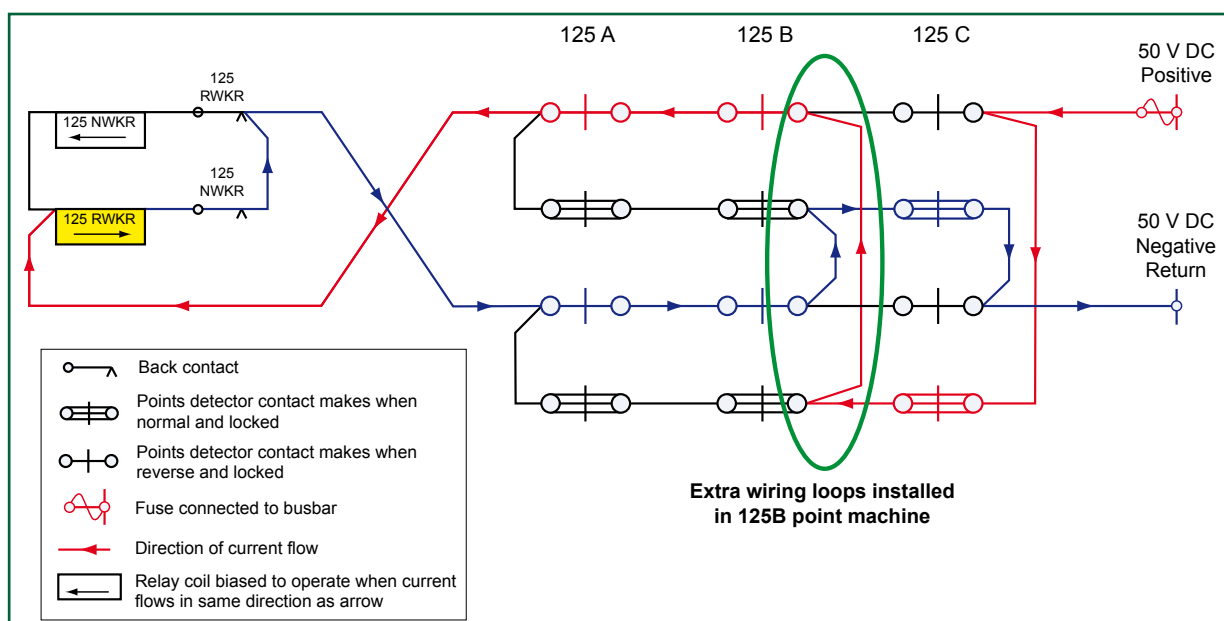


Figure 6: Simplified diagram of 125 points detection circuit showing the wiring error

The site installation and testing of 125B point machine on 17/18 January 2009

The possession arrangements

95 Both the Edinburgh and Glasgow line and the line between Greenhill Upper Junction and Larbert were under an *absolute possession* of the line on 18 January 2009, between planned times of 00:30 hrs and 07:45 hrs. The work being carried out by Lionverge was not the only work being carried out in the possession.

Appointment of the tester

96 It was Lionverge's practice not to appoint the person required to carry out the testing work until the start of the site installation so that it had maximum flexibility to respond to any last minute changes of work it was to undertake. The tester was not appointed until the start of the shift on 17/18 January 2009.

97 Of the four persons in the work gang that night, three of them met the required Network Rail competence standards for carrying out maintenance testing. The fourth person was competent as an installer.

98 One member of the work team was the Lionverge Signalling Manager and the manager of its operation in Scotland. He was also a licensed SMTH tester. His evidence was that although he was the senior Lionverge person in the team during the work carried out on 17/18 January 2009, he was effectively 'the fourth man' of the team; no-one was actually in overall charge because everyone in the team was familiar with what they had to do. The tester once appointed was in charge of the testing activity.

99 Conflicting accounts were received concerning the willingness of the person appointed to do the testing to fulfil that role. The tester's evidence was that he did not volunteer for the task and had to be asked by his manager to carry it out. He stated he was reluctant to do the testing because he had not been able to prepare for the role beforehand; he had not tested a set of points containing three point ends previously; and it was over twelve months since he had tested any points at all. Evidence from two other team members was that the tester did want to carry out the testing role. The tester had however been re-assessed on his competence to test points (paragraph 117) and was therefore certified competent for the testing involved.

Site lighting

100 Site lighting supplied by power from a petrol generator was used to illuminate the installation of the point machine. The subsequent point detection and correspondence testing was carried out using head torches to provide illumination.

101 There was no other site lighting available or lighting installed inside location case 17/2C, containing the detection relays for 125 points (appendix F), and no sources of external light to provide any illumination.

The weather conditions during the testing

102 The RAIB obtained a weather report for the Greenhill area for the night of 17/18 January 2009. This reported that the weather at Greenhill was breezy with clear spells and occasional wintry showers, the main showers occurring just after 21:00 hrs and again at around 05:00 hrs.

103 Between 04:30 hrs and 05:10 hrs there was a brief wintry shower lasting for 10 to 15 minutes which is estimated to have given rise to between 5 and 15 mm of snow lying on the ground. During the rest of this period, the skies were clearer, and it was dry. It was also breezy with air temperatures that were close to, but a little above, zero Celsius.

104 The period of snow coincided with when the point detection and correspondence testing was being carried out (the significance of this is covered in the Analysis section, paragraph 159).

The testing carried out

105 Witness evidence was that the tester did not wire count 125B point machine as required by maintenance test plan PC01.

106 The out of correspondence test (paragraph 57) required the three point ends, 125A, 125B and 125C, to be manually operated at different times, and the points to be operated from the signal box. During this test, witness evidence was that the four staff were located as follows:

- one person at the switch diamonds to operate 125B and 125C as required;
- one person at 125A to operate them as required;
- one person (the Lionverge manager) in the signal box to operate the points using the individual points switch; and
- the tester at location case 17/2C to observe the operation of the detection relays.

107 Following the incident, the RAIB found that the relay case containing the detection relays was in good condition and the position of the contacts could clearly be seen inside the case. The relays are serviced every 10 years and the last service date prior to the incident was on 29 November 1999.

108 The physical layout of the site is shown in figure 7. This shows that it is 187 m from location case 17/2C to the switch diamonds, 72 m to the point machine at 125A points and 44 m to the signal box.

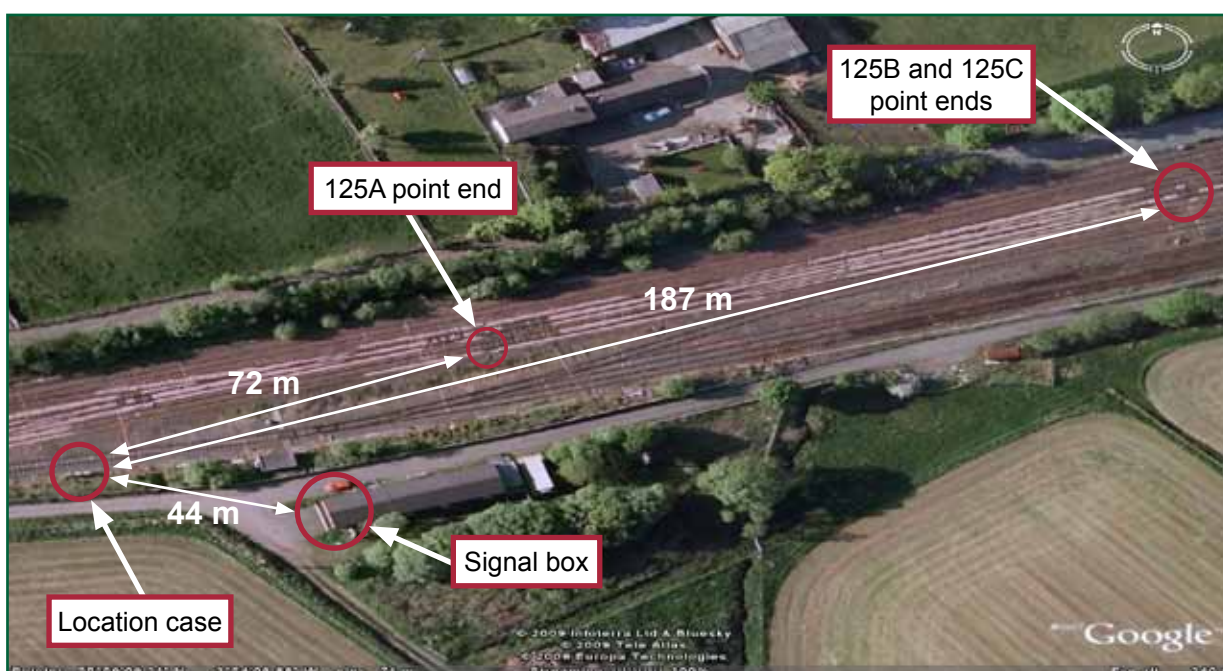


Figure 7: Site layout at Greenhill Upper Junction

- 109 Other than 'face-to-face' speech, the only means of communication between those present on site was by mobile phone between the tester and the person in the signal box; a third mobile phone had been available, but its battery had become flat. Evidence was given that the tester had to walk away from the location case on occasions to request the person at the switch diamonds to manually operate the point ends and to confirm when they had completed their travel.
- 110 Evidence was given that the Lionverge manager in the signal box was there to take phone calls from the tester and operate the points as required so that the signaller did not need to do so. This apparently followed a complaint by a signaller at a different signal box that Lionverge's testing work was causing too much work for them.
- 111 Evidence was given that part way through the out of correspondence testing, the Lionverge person in the signal box shouted to the person at 125A points that the testing was finished and the cover should be re-fitted to the machine. A different account was that this intervention was to request that the cover be re-fitted to prevent the ingress of snow.
- 112 The evidence from witness interviews was that for steps 3 and 5 (paragraph 57), the detection relays and the signaller's panel indications were checked, although the SMTH does not explicitly state whether this is required and what exactly is meant by 'check they (the points) indicate out of correspondence'.

The tester's working hours

- 113 The tester's working time during the week before 17/18 January 2009 is shown in table 2:

Date	Day	Start time	Finish time
10/01	Saturday	23:59 hrs	08:20 hrs (Sunday)
11/01	Sunday	Off	Off
12/01	Monday	At home, not required for work	At home, not required for work
13/01	Tuesday	08:00 hrs	18:00 hrs
14/01	Wednesday	08:00 hrs	18:00 hrs
15/01	Thursday	Off	Off
16/01	Friday	Off	Off
17/01	Saturday	23:00 hrs	08:00 hrs (Sunday)

Table 2: hours worked by the tester in the week before 17/18 January 2009

- 114 The tester gave evidence that so far as he could remember, he had had a normal night's sleep during Friday night 16 January into Saturday 17 January, but he did not then obtain any further sleep before going to work for the Saturday night shift at Greenhill Upper Junction. He also stated that the quality of his sleep during the previous week had been adversely affected by events in his personal life.

115 Use of the Health and Safety Executive's Fatigue and Risk Index, a tool for assessing the relative risk from fatigue associated with shift work, gave a fatigue index score of 31 for the 17/01 shift. This is well below the threshold values of 40 – 45 for night shifts which indicate a high risk of fatigue. The Fatigue and Risk Index does not however take account of disturbed sleep patterns.

Competence of the tester

- 116 The tester had worked for Lionverge for about seven years, having joined from outside the railway industry. He had done most types of signal engineering work during that period.
- 117 Lionverge trained the tester by sending him on training courses, including courses on maintenance testing. Following these he was mentored, during which the tester was required to demonstrate his competence. He was required by Network Rail standards to undergo a recertification in SMTH competence every two years, and this was most recently done following attendance at a training company on 6 June 2008.
- 118 This recertification included carrying out the point detection and correspondence test in which the point detection relays were required to be observed continuously during the manual operation of the points so that their change in state could be correctly checked.
- 119 The tester did not test any points between the date of his SMTH recertification and the work at Greenhill Upper Junction on 17/18 January 2009.
- 120 According to their own standards, Lionverge reviewed the competence of their staff each year and issued an authority to work card following this. The tester's competence was last reviewed in this way on 10 July 2008.
- 121 There was no specific link between the Lionverge process of assessment and the licensing requirements of the Institution of Railway Signal Engineers, but it was their policy that all staff should be so licensed, as required by Network Rail company standard NR/SP/SIG/10160 (paragraph 68).

Updating of maintenance drawings

- 122 Following site installation and testing, the maintenance copies of the wiring diagrams were annotated by hand with the changes shown in red ink. This was principally to show the inclusion of the disconnection box in the tail cables to each set of point ends and to cross out the internal circuitry of the previously fitted HW1000 point machine. Separate drawings were left inside the newly fitted HW2000 point machines showing their internal circuitry.
- 123 Network Rail company standard NR/GN/SIG/11701 'Signalling design: production guidance' states that temporary maintenance copies should be replaced with a final record copy 'within an appropriate timescale', which is not defined further.
- 124 Following the incident on 22 March 2009, there were maintenance drawings in the relay room at Greenhill annotated with alterations that had been carried out as a result of the first phase of the work in early 2008 and, therefore, still to be updated.
- 125 Evidence was obtained that there was a backlog of drawings waiting to be updated all over Network Rail generally.

125C point ends left on manual on 22 March 2009

126 Figure 8 shows the route that was taken by the trolley used to transport the point machine from the access point to 126A point ends. This required 125C point ends to be manually operated to the reverse position.

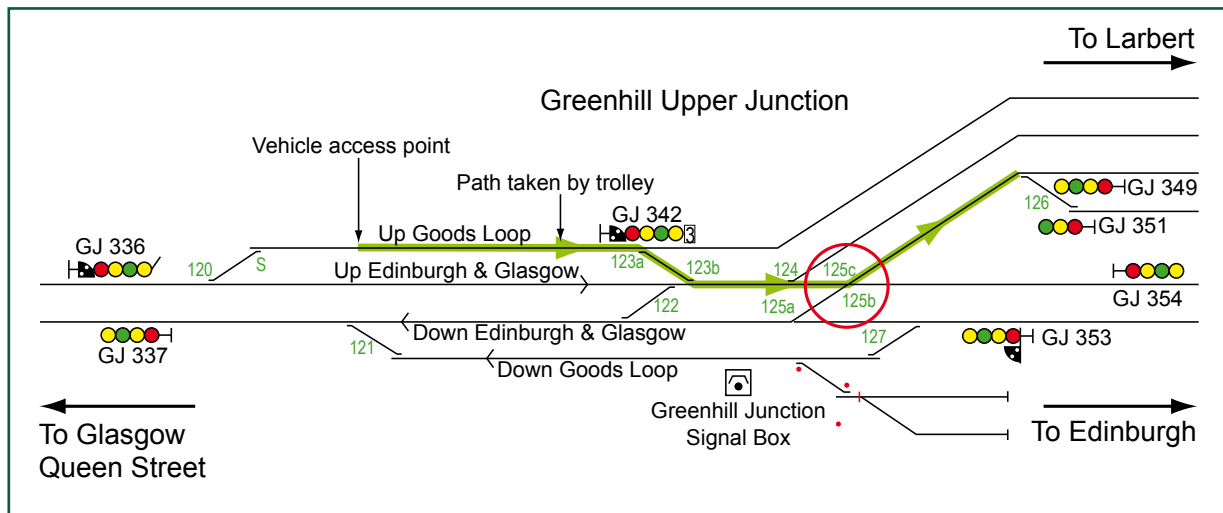


Figure 8: Route taken by trolley over 125C points on 21/22 March 2009

127 Manually operating 125C point ends to the reverse position, with the other ends normal, should have caused the out of correspondence light to flash on the signaller's panel (figure 9), when 125C point ends were detected in the reverse position. The wiring fault would have prevented this indication of out of correspondence occurring, but the signaller did not notice this (there was no requirement that he had to check this).

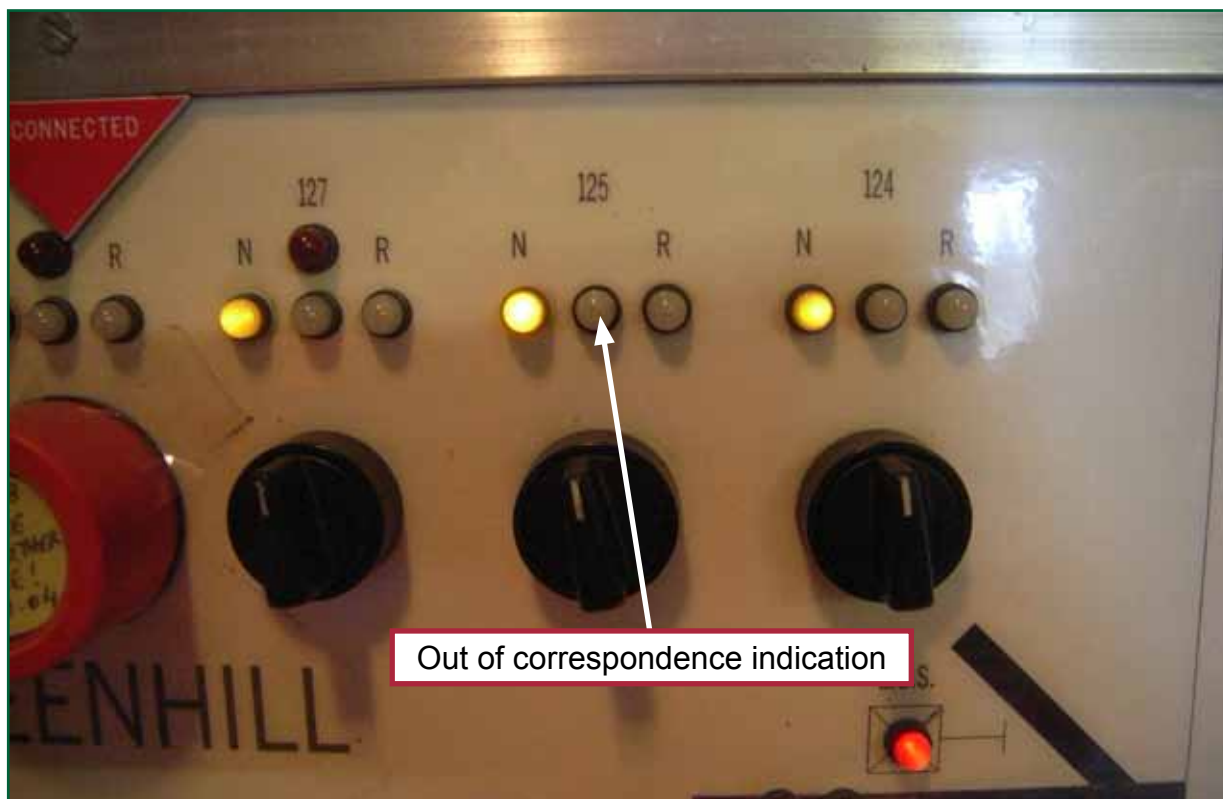


Figure 9: Panel indications relating to points detection

- 128 Following the work, after 125C point ends had been manually operated to the normal position, Lionverge's staff asked the signaller to operate the points reverse and back to normal using the individual point switch. According to witness evidence, this appeared to indicate that the points were operating normally, but because of the wiring error, the failure of 125C point ends to move was not apparent to the signaller.
- 129 When the signaller operated 125 points, there was no-one on the ground in the vicinity of 125C point ends to check whether or not they actually moved. There was no reason or requirement for anyone to check that the points actually moved because no work had been performed on these points. 125C points would not have moved because they had been left in manual mode (paragraph 28).
- 130 The error made in leaving 125C point ends isolated revealed the wiring fault after train 2N50 trailed through them. If this had not occurred, the wiring fault could have remained undetected for many more months.

Monitoring and audit

- 131 Lionverge is qualified under the Link-up scheme, which is a railway industry scheme to ensure that suppliers working on Network Rail's infrastructure have undergone a single common qualification process and therefore demonstrate that they are competent to work on the railway.
- 132 Under the Link-up arrangements, suppliers are required to be audited to an annual frequency by a Link-Up contracted auditor using questions set by Network Rail. The date of the last Link-up audit on Lionverge was 25 July 2008.
- 133 Lionverge is also certificated under standard BS EN ISO 9001:2000 'Quality management systems – Requirements' demonstrating that the company has the quality management systems in place which aim to ensure that it is able to consistently satisfy Network Rail's requirements.
- 134 The depot at Falkirk had its own ISO 9001:2000 certificate that was issued on 9 March 2004. The depot was required to be audited on an annual basis to maintain the currency of the certificate and date of the last such audit, carried out by NQA, an assessment, verification and certification body, was carried out on 9 October 2008.
- 135 The audit did not identify that the unofficial checking process at Falkirk depot (paragraph 92) was not covered by any procedure. It reviewed the method statement for the phase 2 works but this made no reference to the work carried out at Falkirk (paragraph 84) and stated that all the works would be tested in according with SMTH procedures. No significant issues were found as a result of this audit.
- 136 Records obtained showed that Lionverge undertook monthly surveillance visits on its staff while working to check that the necessary documentation was available, and the required personal protective equipment was being used. Prior to the installation of the 125B point machine on 17/18 January 2009, Lionverge made surveillance visits relating to the HW1000 to HW2000 point machine renewal project to staff working at Cadder on 7 September 2008 and at Gartshore on 9 November 2008. No corrective action was required following these visits.

Network Rail's contract management

- 137 A Network Rail service delivery manager, who was part of the team which selected Lionverge to undertake the work, managed the HW1000 renewal project. The service delivery manager agreed the method statements for each of the two phases of the project and undertook site inspections during the phase 1 works to ensure the works were delivered to an acceptable quality standard.
- 138 The inspections were of a general nature, for example to check the satisfactory fixing of disconnection boxes, that cables were labelled and secured properly, and that covers were correctly replaced on cable troughing routes. The checks did not include removing the covers from point machines and the counting of wires.
- 139 The service delivery manager carried out one of the inspection visits during the phase 1 works at night while Lionverge was working on site.
- 140 During the phase 2 works, the service delivery manager undertook surveillance visits while Lionverge was working at Cadder and Gartshore. He visited the works at Greenhill Upper Junction during the night of 7/8 February 2009 while the installation of a point machine was taking place, but before the testing was carried out.

Previous occurrences of a similar character

- 141 The accident at Clapham Junction on 12 December 1988 caused the deaths of 35 people and injuries to nearly 500 more. It occurred when a signal that should have been at red, protecting a train in front, erroneously showed a proceed aspect. The accident was investigated by Sir Anthony Hidden QC and the findings were published¹.
- 142 The failure arose from work being carried out as part of the Waterloo Area Resignalling Scheme. A relay contact was by-passed when a wire which had been disconnected from another relay contact in the circuit, and which had not been disconnected at the fuse end, came back into contact with the relay terminals. The result of this was that the occupation of a track circuit by a train did not turn a signal back to red as it should have done.
- 143 The failure would have been prevented if a wire count had been carried out and the report recommended:
- British Rail shall urgently ensure that an independent wire count is carried out as a matter of practice during testing. It shall be the responsibility of the person in overall charge of testing to ensure and to document that an independent wire count has been done.
- 144 The report also led to the separation of the installation and testing roles based on the philosophy that testers should not have been involved in carrying out the work being tested; if an installation error has been made, the same person testing it could repeat the same error.

¹ Investigation into the Clapham Junction Railway Accident, Anthony Hidden QC, ISBN 0 10 108202 9

- 145 The only previous incident that the RAIB has been able to find where the testing of points was a factor was the wrongside signalling failure that occurred at Kenilworth on 23 June 1997. The incident occurred when a signal indicated that an approaching train would be routed along the main line but the facing points were in fact set for the diverging route (the normal position of the points) into the passing loop. The indication in Coventry signal box was that the points were in the reverse position. A wiring defect consisting of two crossed pairs of wires (which had the effect of cancelling the error out) had existed for many years and the work carried out eliminated one of the crossed pair of wires causing a fault in the detection circuit. When the signalling technician carried out a correspondence test, he used a sketch that showed the lie of the points incorrectly. On completion of the work, the state of the detection relays and the indications in the signal box did not correspond with the actual lie of the points.
- 146 Railtrack (the predecessor organisation to Network Rail) held a formal inquiry and made six recommendations. These included changes to railway rules governing work on signalling equipment and that signallers and technicians should have an unambiguous means of agreeing the lie of points. *HM Railway Inspectorate* also investigated the incident and prosecuted the contractor responsible for the work.
- 147 An incident where the work taking place was planned to be undertaken using the SMTH but should have used processes under the SWTH led to a wrongside failure of a track circuit at Derby London Road Junction on 17 September 2005 and caused a track circuit to show clear when occupied. The incident was caused by the fitment of straps to a relay false feeding it, and causing it to be energised when it should not have been. Network Rail investigated the incident and made recommendations. One of these was that Network Rail should consider improving the demarcation between SMTH and SWTH work. This led to Network Rail issuing a Notice Board instruction dated December 2007 to clarify under what circumstances SMTH processes may be used as opposed to SWTH (paragraph 44). There is no evidence that this instruction had any influence on the planning of the works at Greenhill Upper Junction because it was issued after the works had been planned (paragraph 71).

Analysis

Identification of the immediate cause²

148 The immediate cause of the incident on the 22 March 2009 was that 125 points were detected in the reverse position by the signalling system with 125C point ends in the normal position. This allowed the protecting signal to clear for train 2N50 which subsequently trailed through 125C point ends.

Identification of causal³ and contributory⁴ factors

The pre-wiring of the point machine for 125B point ends at Falkirk depot

149 A causal factor of the incident was that extra wiring had been incorrectly installed in the point machine for 125B point ends at Lionverge's Falkirk depot.

150 None of the maintenance testing processes in the SMTH for checking and testing were carried out at Falkirk depot. A wire count could have been carried out and a written record produced confirming this had been done, but it was Lionverge's policy that all the testing required by the SMTH would be carried out on site following installation.

151 Evidence was given that an informal checking system did exist at Falkirk depot (paragraph 92), but there is no evidence whether or not this was applied to the point machines for 125 points and even if this informal system was applied, it did not find the incorrect wiring. There were no records of any such checking.

152 A causal factor therefore is that the extra wiring was not detected before 125B point machine was installed on site at Greenhill Upper Junction on 17/18 January 2009 because there was no formal procedure in place at the Falkirk depot to carry out any checks or tests.

153 The installation of the wiring to the point machines for 125B and 125C point ends was carried out to a single A3 size wiring diagram showing both machines on it (paragraph 93 and appendix D); previous practice was to produce specific, separate, drawings for each machine.

154 Witness evidence was that the drawing shown in appendix D was folded back on itself and placed in a plastic wallet. This resulted in the section of the drawing showing 125B on one side and the section of the drawing showing 125C on the other side.

² The condition, event or behaviour that directly resulted in the occurrence.

³ Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

⁴ Any condition, event or behaviour that affected or sustained the occurrence, or exacerbated the outcome. Eliminating one or more of these factors would not have prevented the occurrence but their presence made it more likely, or changed the outcome.

- 155 Witness evidence suggested that the person who installed the incorrect wiring in the machine for 125B point ends read the section of the drawing showing the point machine for 125C point ends and installed the extra wiring required in the machine for 125C point ends in the machine for 125B point ends. There is a further possibility that the person who wired the point machine for 125B point ends thought he was wiring the machine for 125C point ends because the machines were not clearly identified.
- 156 Showing the wiring changes needed to both 125B and 125C point machines on the same drawing was a probable causal factor.

Site testing of 125B point ends on 18 January 2009

- 157 The site testing was not carried out correctly according to maintenance test plan PC01 because a wire count was not carried out and the state of the detection relays was not correctly observed during the out of correspondence test. This was a causal factor because if the site testing had been carried out correctly, the wiring error in 125B point machine would have been discovered and the incident on 22 March 2009 would not have occurred.
- 158 The tester was not appointed until the start of the shift on 17/18 January 2009 (paragraph 96). He had not tested points for over 12 months and had never previously tested points with three point ends (paragraph 99). If he had been told beforehand that he was to carry out the testing, he would have had the opportunity to revise his knowledge of points testing from the SMTH, think about how he would organise the testing, and arrive at work mentally prepared to carry it out. Not appointing the tester until the start of the shift was a contributory factor.
- 159 The weather conditions during the testing were poor: there was a brief snow shower just when the point detection and correspondence testing was being carried out and it was cold (paragraph 103). It was also dark. The falling snow, cold temperature and darkness were a possible contributory factor because they could have made it more difficult to concentrate on the requirements of the testing.
- 160 Despite the relatively low Fatigue Index resulting from use of the Fatigue and Risk Index (paragraph 115), the tester would probably have been feeling tired when doing the testing because of the length of time he had been awake since sleep during the night of 16/17 January 2009 (paragraph 114). The testing was also carried out at a time of day when the body's internal clock, known as the circadian rhythm, causes alertness to be at its lowest⁵. The tester also gave evidence that the quality of his sleep had been adversely affected during the week before, a factor not taken into account by the Fatigue and Risk Index. The RAIB has concluded that the tester's fatigue could have degraded his ability to focus properly on carrying out the testing and was therefore a possible contributory factor.

The wire count

- 161 The additional, incorrect, wiring would have been discovered if the tester had carried out the wire count required by maintenance test plans PC01 and CA03.

⁵ The Development of a Fatigue/Risk Index for Shift Workers, Research Report 446, prepared for the Health and Safety Executive, available from www.hse.gov.uk

- 162 Based on witness evidence, the tester's decision not to carry out a wire count was probably influenced by the fact that he was aware an informal checking system was in operation at Falkirk depot (paragraph 92). He therefore thought that a wire count had already been carried out and there was no longer a requirement to do one on site.
- 163 The tester also stated in evidence (although this could not be confirmed by other evidence) that he was told by his three work colleagues on site that the machine for 125B point ends would already have been pre-tested at Falkirk depot. This pre-testing was generally assumed to consist of a wire count, so the tester decided there was no need to do one again, even though there was no written record that the wire count had been done.
- 164 In the absence of any written record confirming a wire count had already been done, the tester should have carried out the wire count required by the SMTH, but he made the decision that a wire count was unnecessary.
- 165 A wire count would have taken about 15 to 20 minutes, so there would have been sufficient time for the tester to have carried it out.

The point detection and correspondence test – the correspondence test

- 166 The RAIB obtained a download from the datalogger fitted in the relay room at Greenhill and analysed the data (appendix E) to establish whether the data matched the steps required in carrying out the point detection and correspondence test in NR/SMTH/Part 3/Test B8.
- 167 The data indicates that the testing started at 04:33:34 hrs with the points being operated in a way that is consistent with the correspondence test (paragraph 55) being carried out. This was completed at 04:40:10 hrs and would not have revealed the wiring fault in 125B point ends.

The point detection and correspondence test – the detection test

- 168 The data then indicates that the detection test (paragraph 56) started at 04:40:36 hrs and finished at 04:43:56 hrs with the breaking of the normal detection contacts in the three 125 point ends a total of 24 times. The points were then operated to the reverse position and the reverse detection contacts were broken 24 times between 04:45:13 hrs and 04:46:46 hrs.
- 169 The SMTH requires each normal and detection contact to be broken three times but witness evidence was obtained that the railway industry (Network Rail and its contractors) does not have a clear position on how the detection test on an HW2000 point machine should be done.
- 170 One interpretation is that the 'H' shaped piece (appendix F, paragraph 7) forms one contact and the contact should be broken once at 'A', once at 'B' and a third time at either 'A' or 'B' (appendix F, figure 14). When broken for the third time, this contact should be broken for at least 10 seconds to test that the 'slow to energise' relay in the motor decision circuit, which stops the points motor from running for too long, energises after approximately 7.5 seconds (breaking a detection contact causes the motor to run).
- 171 Another interpretation is that each spring contact forms one contact. Therefore, each spring contact at 'A' is broken three times and then each spring contact at 'B' is broken three times. Again, for one of these breaks, the contact should remain broken for at least 10 seconds to test operation of the 'slow to energise' relay.

- 172 In either case, both the incoming wiring to contact 'A' and outgoing wiring from contact 'B' should be broken separately.
- 173 The data indicates that each contact, in each of the three 125 point machines, was broken twice – rather than three times – and the operation of the 'slow to energise' relay was not tested. Again, this test would not have revealed the wiring fault present in 125B point ends.

The point detection and correspondence test – the out of correspondence test

- 174 The points were then operated to the normal position, as required for the out of correspondence test, at 04:47:30 hrs. In the context of the permutation table in table 2, the data is consistent with 125A point ends being end 1, 125B point ends being end 2 and 125C point ends being end 3. The sequence of carrying out the test is described in paragraphs 57, 58 and 61 and the location of staff during the testing is described in paragraph 106 (see figure 7, also).
- 175 The RAIB's analysis of the data shows that the wiring fault could have been discovered on three occasions during the out of correspondence test by correct observation of the position of the detection relays:
- a. during stage 5 of the test with 125B and 125C point ends isolated, and assuming that 125B was manually operated first (paragraph 57, step 4), detection would have been incorrectly obtained before manually operating the 125C end;
 - b. during stage 7 of the test with 125C point end isolated, reverse detection was incorrectly obtained when the points were operated to the reverse position using the individual point switch in the signal box; and
 - c. after 125C point end was manually operated to the reverse position and the points operated to the normal position using the individual point switch in the signal box, normal detection was incorrectly obtained with 125C point end still in the reverse position.
- 176 The RAIB has concluded that it was unlikely that the tester made an error in observing the position of the detection relays while at the location case; the condition of the relay case was good, with the position of the detection relays clearly visible inside (paragraph 107 and appendix F, paragraph 4). It is likely that the incorrect observation of the relays occurred because the tester was not always at the location case to observe the relays. This could have been for the following possible reasons:
- a. he was not aware that he had to continuously observe the detection relays when the points were manually operated; or
 - b. he had to leave the location case in order to communicate with the person positioned at the switch diamonds who was manually operating 125B and 125C point ends.

The tester not correctly observing the state of the detection relay positions during the out of correspondence testing was a causal factor.

- 177 The only long range communications in use was by mobile phone between the tester and the person in the signal box, who operated the individual point switch controlling 125 points (paragraph 109). This meant that the only available means of communicating with the persons at 125A and 125B/C point ends was face-to-face.
- 178 The consequence of this was that, because of the long distances on the site (figure 7), the tester was not able to communicate verbally from his position at the location case with the person who was stationed to manually operate 125B/C point ends. The tester sometimes had to leave the location case where the detection relays are housed in order to speak to the person at the switch diamonds.
- 179 With reference to paragraph 176a, evidence was given that there is a common misconception among staff concerning steps 4 and 6 of the out of correspondence test, which is that this test is to look for detection towards the end of travel, whereas the actual aim is to continuously check that there is no detection until the point ends are in the correct position and the facing point lock is engaged. This means checking the state of the relay throughout the movement of the point ends, including at the start of the test before any point ends are moved manually. The tester should then watch the detection relay throughout.
- 180 Witness evidence was that during the tester's recertification of SMTH competence (paragraph 118), he would have been tested on the requirement to continuously observe the state of the detection relays while the point ends were being manually operated.
- 181 For the first occasion (paragraph 175a), when an incorrect state of the detection relays could first be seen, it is likely that the tester was away from the location case so that he could speak to the person at 125B/C point ends to ask them to manually operate the points to a different position (paragraph 109). While doing this, he was not in a position to observe the detection relays and therefore did not see detection incorrectly obtained when 125B point end had been manually operated, before 125C was manually operated.
- 182 In the case of paragraph 176b, the tester could have been at the location case to observe the position of the detection relays when 125 points were operated by the individual point switch in the signal box. There were two occasions (paragraphs 175b and c) when the fault would have been apparent under these circumstances. The RAIB has concluded that the tester was not at the location case to observe the relays, and he was probably away from the location case so that he could ask the person at the switch diamonds to manually operate 125C point ends.
- 183 This could have been to save time and complete the testing more quickly, although sufficient time remained in the possession (paragraph 95) to complete the testing properly. The weather was poor when the out of correspondence test was being carried out (paragraph 159), the tester would probably have been tired (paragraph 160), and there was the intervention of the Lionverge manager, located in the signal box, part way through the testing, saying that the cover should be re-fitted to 125A point machine (paragraph 111). These factors may have influenced the tester to complete the testing as soon as possible.

- 184 The out of correspondence test was completed at 05:05:36 hrs, 18 minutes 6 seconds after being started. Network Rail's HQ staff advised that around 25 to 28 minutes is probably a more realistic time that is required for carrying out the test on a three ended set of points. This provides further evidence that the testing was rushed so that it was not done correctly.
- 185 The precise method of carrying out steps 3 and 5 of the out of correspondence test is not specified in the SMTH and is open to interpretation by training providers. These steps of the test do not state whether the checks required should be of the detection relays only, or also of the indications in the signal box. Different views were obtained on this: some that the check should be of the relays (as is explicitly stated for steps 4 and 6), and others that as the signaller is requested to carry out an action at the panel, the subsequent check to establish what is indicated should be carried out by asking the signaller to report back what is indicated on the panel rather than by checking the position of relays.
- 186 The Lionverge policy was that steps 3 and 5 should be checked at the detection relays and not at the panel indications. Witness evidence was that the Lionverge manager in the signal box, who was himself a licensed SMTH tester (paragraph 98), observed the panel indications, when he operated the individual point switch for 125 points, and advised the tester. At the same time, the Lionverge manager's evidence was that he did not monitor the progress of the different stages of the testing, and therefore played no part in deciding whether or not the indications shown on the signaller's panel were correct.
- 187 If the panel indications had been correctly responded to during the out of correspondence testing, the fault caused by the incorrect wiring would have been obvious in the case of paragraphs 175b and c. Every time the points were called to the normal or reverse positions, the signaller's panel should have shown an out of correspondence indication (paragraph 57), but there were two occasions when it would not have done. The RAIB has not been able to establish why these indications were not correctly responded to and why, if the Lionverge manager correctly advised them to the tester, the latter did not realise they were incorrect (the tester should have realised this as well if he was correctly observing the detection relays, but the indications shown on the panel were another opportunity to discover the faulty wiring). The incorrect response to the panel indications was a causal factor in the incident.
- 188 Lionverge had decided to provide one of its staff in the signal box to liaise with the signaller during the testing because of a signaller's complaint elsewhere (paragraph 110), but there was no evidence that Network Rail required this.
- 189 This was an unnecessary use of resources and the person in the signal box could have been utilised to help and support the tester outside.
- 190 Of the three opportunities during the out of correspondence testing to detect the wiring error, in each case it is almost certain the tester was not at the location case to observe the detection relays. In the first instance, he had to be away from the location case to speak to the person operating 125B and 125C point ends; in the second and third instances, the tester was probably not at the location case because he was already walking towards the switch diamonds to ask the person there to operate 125C point ends. It is likely that this was to complete the testing more quickly.

191 Furthermore, the incorrect panel indications shown during two of the tests were not correctly responded to by the tester, if the person in the signal box correctly advised him of what the panel indications were.

125C point ends left on manual on 22 March 2009

192 Not switching 125C point ends back onto power after they had been used on manual to facilitate the movement of a trolley on 22 March 2009 (paragraph 28) was a causal factor in the incident. However, this omission caused the fault in 125B point ends to be revealed with relatively benign consequences (paragraph 32).

Identification of underlying factors⁶

193 The processes in the SMTH are written from the perspective of carrying out work on site and do not explicitly cover pre-installation work of the sort done at Lionverge's Falkirk depot. However, the SMTH does not exclude this, or the carrying out of some testing off-site before site installation. The focus of the SMTH on site work could have resulted in the lack of formal processes (paragraphs 90 to 94) in place covering the work undertaken at Falkirk depot.

194 Network Rail does not require the completion of the specific stages of the SMTH to be documented; only the completion of a test plan such as PC01. Under the SMTH, there is therefore no specific process to record the extent of any partial testing that has been carried out in advance of site work. The SMTH not requiring the documentation of stages of testing was an underlying factor of the incident.

195 The project to renew the HW1000 point machines was specified in an engineering project specification (paragraph 70) on the basis that processes in the SMTH would be used. However, when further planning was carried out, it became clear that what Network Rail wished to achieve was beyond what could be carried out using processes in the SMTH. Network Rail therefore reduced the scope so that the work could be done under the SMTH (paragraph 78).

196 The SMTH did not require the production of separate drawings for the work done at Falkirk depot, which might have avoided the wiring error that was made. Lionverge had to use drawings for the work at Falkirk that were copies of the maintenance drawings kept in Greenhill Junction relay room (paragraph 90). Lionverge had to obtain these by taking digital images of them; specific drawings for the planned work being carried out were not supplied by the client organisation, Network Rail. The lack of separate drawings at Falkirk was an underlying factor in the incident.

197 Network Rail did not require, and Lionverge did not plan, the organisation of the testing in advance by considering, and documenting in a method statement, such things as the number of staff required, where they should be positioned, who would be in charge of the testing work and the means of communication to be used (paragraph 86). Lionverge considered that four staff was the minimum necessary to renew a point machine on site, but it did not take into account the extra work arising from testing a three ended set of points. The lack of planning of the organisation of the testing was an underlying factor in the incident.

⁶ Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

198 Network Rail does not express a preference that, for project type work carried out under the SMTH, the testing should be carried out in advance so far as is possible. Where testing can be carried out in advance in a workshop environment rather than on site, this should normally be the preferred option. Network Rail not expressing a preference in its process documents that pre-testing is carried out prior to site installation as far as possible, and therefore obviating the need to do it on site, was an underlying factor in the incident.

Other factors for consideration

199 Maintenance copies of drawings held in the relay room at Greenhill had not been updated following alterations made well over 12 months earlier. Network Rail company standard NR/GN/SIG/11701 states that final updates should be issued to an appropriate timescale without giving guidance on what such a timescale should be. Evidence was given that there was a current backlog in Network Rail of updating drawings (paragraphs 122 to 125).

200 The railway industry does not have a clear view about how the detection test should be carried out in the case of HW type point machines (paragraphs 169 to 172).

201 There is a common misconception among staff concerning steps 4 and 6 of the point detection and correspondence test, which is that this test is to look for detection towards the end of travel, whereas the actual aim is to continuously check that there is no detection until the point ends are in the correct position (paragraph 179).

202 The out of correspondence test in the SMTH does not specify whether or not the panel indications should be monitored (paragraph 185), and this is not covered in training courses.

Conclusions

Immediate cause

203 The immediate cause of the incident on the 22 March 2009 was that 125 points were detected in the reverse position by the signalling system although 125C point ends were in the normal position. This allowed the protecting signal to clear to a proceed aspect for train 2N50 which subsequently trailed through 125C point ends.

Causal factors

204 Causal factors were:

- a. Extra wiring was incorrectly installed in the point machine for 125B point ends at Lionverge's Falkirk depot. This point machine was installed on site at Greenhill Upper Junction on 17/18 January 2009 (paragraph 149, recommendation 1).
- b. The extra wiring was not detected before 125B point machine was installed on site at Greenhill Upper Junction on 17/18 January 2009 because there was no formal procedure in place at the Falkirk depot to carry out any checks or tests (paragraph 152, recommendation 1).
- c. The site testing carried out at Greenhill Upper Junction on 18 January 2009 was not carried out correctly (paragraph 157, recommendation 2) because:
 - the tester did not carry out a wire count of the point machine fitted to 125B point ends (paragraph 161) and
 - the tester did not correctly observe the state of the detection relay positions during the out of correspondence testing (paragraph 176).
- d. The indications on the signaller's NX panel were not correctly responded to during the out of correspondence testing (paragraph 187, recommendation 3a).
- e. 125C point ends were not switched back onto powered operation on 22 March 2009 (paragraph 192).

205 The following factor was considered to be probably causal:

- a. the installation of the wiring to the point machines for 125B and 125C point ends was carried out to a single wiring diagram that showed both machines on it (paragraph 156, recommendation 4).

Contributory factors

206 A contributory factor was:

- a. the tester was not appointed until the start of the shift on 17/18 January 2009 (paragraph 158, recommendation 2).

207 The following factors were considered to be possibly contributory:

- a. it was dark and the weather conditions during the testing were poor: there was a brief snow shower just when the point detection and correspondence testing was being carried out and it was cold (paragraph 159); and
- b. the testing was carried out at a time of day when the tester would probably have been tired because of the length of time he had been awake since sleep during the night of 16/17 January 2009. It was also a time of day when levels of alertness are at their lowest (paragraph 160).

Underlying causes

208 The underlying causes were:

- a. the SMTH not requiring the documentation of stages of testing; only the completion of a complete test plan such as NR/SMTH/Part 4/PC01 (paragraph 194, recommendations 4 and 5);
- b. the lack of separate drawings for each point machine wired at Falkirk depot (paragraph 196, recommendation 4);
- c. the lack of planning of the organisation of the testing (paragraph 197, recommendations 2 and 4); and
- d. Network Rail not expressing a preference in its process documents that pre-testing is carried out prior to site installation as far as possible (paragraph 198, recommendations 1 and 4).

Additional observations⁷

209 The following observations are made:

- a. The out of correspondence test in the SMTH does not specify whether or not the panel indications should be monitored as part of the test. This is also not fully covered in training courses (paragraph 185, recommendation 3a).
- b. The railway industry does not have a clear view about how the detection test should be carried out in the case of HW type point machines (paragraph 169, recommendation 3b).
- c. There is a misconception amongst staff about how the detection relays should be observed during the manual operation of points during the out of correspondence test (paragraph 201, recommendation 3c).
- d. Annotated copies of maintenance drawings at Greenhill had not been updated and there was said to be a backlog generally in updating drawings (paragraph 199, recommendation 6).

⁷ An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the incident but does deserve scrutiny.

Actions reported as already taken or in progress relevant to this report

210 Network Rail carried out its own investigation of the incident and concluded that the immediate cause of the incident was the failure to correctly wire the detection circuitry in 125B point machine and the subsequent failure to adequately carry out the requirements of the SMTH. Network Rail made six recommendations and one local action. The recommendations included the following matters:

- The permutation chart in the SMTH (paragraph 61) should be positively filled out at each stage of the out of correspondence testing and should be submitted as part of the testing paperwork.
- If and when pre-wiring takes place in a workshop, the method statement must reflect this, the wiring must be independently checked at this stage by a tester and the test paperwork completed to reflect this fact. The testing check and paperwork should also confirm that the machine is uniquely identified.
- The tester should be pre-allocated to the role sufficiently in advance of the test to be able to understand the paperwork, the arrangements for installation and testing and sign off of the plan prior to the activities taking place.

The local action covered the checking for detection wiring faults of all other works where the tester in the incident was involved. This was completed immediately following the incident and no faults were found (paragraph 34).

Recommendations

211 The following safety recommendations are made⁸:

Recommendations to address causal and contributory factors and other matters observed during the investigation

- 1 *The purpose of this recommendation is to make it clear in maintenance documentation that if installation work covered by maintenance testing arrangements is partially carried out, off site, as pre-work, the work should be independently tested so far as is practicable at that stage. The extent of the testing should be confirmed on a written record that is available for those completing the testing following site installation. A tester should be in overall charge of the testing as required by current standards.*

While maintaining the requirement that one maintenance tester should be in overall charge of the testing, Network Rail should revise its maintenance documentation such as the SMTH to make it explicitly clear that if installation work is carried out off site in advance of site work, this pre-work should be tested if practicable at that stage (paragraphs 204a, b and 208d).

- 2 *The purpose of this recommendation is that for planned project work such as the HW1000 point machine renewal project in Scotland, testing should be planned in advance and not left to the time of site installation.*

Network Rail should revise its procedures so that where planned project work is carried out under the SMTH, the arrangements for testing of the completed works (and any partially completed works) should be planned and documented in advance and briefed to those undertaking the work prior to the commencement of those works (paragraphs 204c, 206a and 208c).

continued

⁸ Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation to enable them to carry out their duties under regulation 12(2) to:

- (a) ensure that recommendations are duly considered and where appropriate acted upon; and
- (b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 167 to 171) can be found on RAIB's web site at www.raib.gov.uk.

- 3 *The purpose of this recommendation is to make clear in maintenance documentation the correct intent and method of carrying out points testing.*

In respect of points testing, Network Rail should clarify and brief their staff as to:

- a. whether or not the signaller's indications should be monitored during the out of correspondence test (paragraphs 204d and 209a);
 - b. the method of carrying out the detection test of HW type point machines (paragraph 209b); and
 - c. the need to continually monitor the detection relays during the manual operation of points when the out of correspondence test is being carried out. The points should be moved at a rate that allows any false operation of the relays during their travel to be observed (paragraph 209c).
- 4 *The purpose of this recommendation is the creation of a process suitable for the installation and testing relating to small-scale enhancement projects, requiring a limited change in the design, such as the HW1000 point machine renewal project in Scotland whose scope had to be reduced to fit the requirements of maintenance testing. The process would contain less onerous requirements than in works testing but more onerous requirements than in maintenance testing.*

Network Rail should consider the introduction of a process that is suitable for planned small-scale enhancement projects of the type originally conceived for the HW1000 point machine renewal project in Scotland. Consideration should be given to the inclusion of the following elements in any new process:

- a project specification;
 - the issue of design drawings;
 - a strategy for the testing, including the resources required;
 - the appointment of the tester in advance;
 - a written test plan; and
 - a system that documents the completion of specific stages of the testing (paragraphs 205a, 208a, b, c and d).
- 5 *The purpose of this recommendation is to enhance the system under which records of work carried out under the SMTH are made, in order to provide better traceability and auditability of what has been done.*

Network Rail should review the adequacy of the system of written records arising from work carried out under the SMTH so that the completion of specific stages of work covered by the SMTH gives rise to specific records of what has been done (paragraph 208a).

continued

- 6 *The purpose of this recommendation is to improve the system by which copies of maintenance drawings, marked with handwritten annotations showing alterations, are updated.*

Network Rail should revise its current system for the updating of amended maintenance drawings with the aim of reducing the time taken to do so. This should include prescribing clear timescales in standards (paragraph 209d).

Appendices

Appendix A - Glossary of abbreviations and acronyms

SMTH	Signalling maintenance testing handbook
SWTH	Signalling works testing handbook

Appendix B - Glossary of terms

All definitions marked with an asterisk, thus (*), have been taken from Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Absolute possession	A period of time during which one or more tracks are blocked to trains to permit work to be safely carried out on or near the Line. It is taken for an agreed period without the facility to run trains in the area during that period until such time as the holder of the possession relinquishes it.*
Alternating traction current	The flow of electrical energy through the overhead line equipment (provided where a railway is electrified) and back through the traction current rail (one of the normal running rails being used for this purpose).*
Back drive	An arrangement of rodding and cranks, hydraulics or torsion drives that transfers some of the motion of the switch toes (the ends of the switch rails) to one or more points further down the points. The system compensates for the flexibility of long switch rails.*
Clear	To change a signal's aspect (ie for a colour light signal, the coloured light displayed) from its most restrictive to a less restrictive aspect.*
Detection contacts	Electrical contacts inside the point machine that close when the points are set and locked in either the normal or reverse positions and cause the appropriate detection relay to be energised.
Diesel multiple unit	A train consisting of one or more vehicles (semi-permanently coupled together) with a driving cab at both ends. Some or all of the vehicles may be equipped with diesel engines to power the axles.
Disconnection box	A small lineside enclosure used to terminate track circuit tails and other similar cables.*
Double cut	A circuit that has relay contacts in both the positive and negative parts of the circuit to provide greater resilience against fault conditions.
Facing direction	Direction of travel over a set of switches (set of points) in which a vehicle can be directed to one of two or more diverging routes.*
Facing point lock	The mechanical device which locks the switch rails in either the normal or the reverse positions and therefore prevents the points being moved once they have been detected as set in the required position and locked.
Geographical route relay interlocking	A type of interlocking in which standard pre-wired assemblies are provided for each signalling function such as a signal, arranged and electrically interconnected in a geographical manner.*

High stability sole plate	A metal plate on which a point machine is mounted that maintains the correct spatial relationship with the stock rails.
HM Railway Inspectorate	Now part of the Office of Rail Regulation, the safety regulator for railways in Great Britain.
Individual point switch	A switch on a signaller's panel that can be used to operate points to the normal and reverse positions. The position of the points is marked by an indication light normal or reverse. A third (flashing) light indicates if the points are out of correspondence.
Interlocking	Controls fitted between points and signals that prevent the signaller from setting conflicting routes. In mechanical signalling this was achieved by locking slides on a locking shelf, which locked conflicting levers. More modern systems use a relay based logic (Route Relay Interlocking), microprocessors or computers to perform the same functions.*
Location case	A small steel cabinet placed at the lineside housing power supplies and other equipment related to signals, track circuits, points and telecommunications.*
Maintenance testing	The processes governing the testing of alterations to previously working and commissioned signalling systems where the design has not been changed.
Manual operation	The operation of a point machine by hand, using a handle, after its motor has been isolated from the electrical supply.
Multiple aspect colour light signal	Signals which convey movement authorities to train drivers by means of coloured lights. These signals are described as having a number of aspects, eg four aspect signal.*
Normal position	One of the designated positions of a set of points; usually the straight ahead position when approached in the facing direction.
NX panel	A signal box panel fitted with buttons for all entrances and exits, plus some intermediate points. To set a route, the signaller depresses the appropriate buttons in front of the train and at its exit point, and a panel processor sets the route, shown in white lights on the illuminated diagram. Trains are shown as red lights.*
Out of correspondence	In relation to points, the situation that exists when a point end is not in the position commanded by the signaller or which incorrectly shows detection.
Points	<p>a) An assembly of switches and crossings designed to divert trains from one line to another.</p> <p>b) Another name for a set of switches. These terms are used interchangeably.*</p>
Point end	A term describing a pair of switch half sets assembled to make a set of points or set of switches.*

Point machine	A generic term for any powered device that operates a set of points (set of switches).*
Possession	A period of time during which one or more tracks are blocked to trains to permit work to be safely carried out on or near the line.*
Protecting signal	A signal that prevents trains from entering a section of route where conflicting movements (any movement of two trains that would force them to occupy the same section of track) may take place.*
Railway Group Standard	A document mandating the technical or operating standards required of a particular system, process or procedure to ensure that it interfaces correctly with other systems, processes or procedures.*
Relay	An electromechanical device that utilises an electromagnet to make and break related sets of electrical contacts. Therefore, one electrical signal can be used to determine the connection or disconnection of many other circuits. Used widely in power signalling, the standard type has a set of Normally Closed (NC) (when the coil of the electromagnet has no current flowing through it) back contacts and a set of Normally Open (NO) front contacts. There are many types and varieties.*
Relay room	A building used to house relays and other signalling and telecommunications equipment.
Reverse position	The opposite position of a set of points to their normal position.
Switch blade	(see 'switch rail')
Switch rail	Also known as switch blade. The thinner movable machined rail section that registers with the stock rail (the fixed rail in a set of points) and forms part of a switch (points) assembly.*
Switch diamonds	A diamond crossing without check rails in which the obtuse point rails move, thus becoming (in pairs with similar rails in the opposite obtuse crossing) switch rails.*
Tail cable	A heavy duty insulated conductor linking signalling equipment located on or close to the track (such as point machines) with disconnection boxes and location cases.*
Track circuit	An electrical or electronic device used to detect the absence of a train on a defined section of track using the running rails in an electric circuit.*
Track circuit block	A signalling system where the line is proved clear to the end of the overlap beyond the next signal using track circuits.*
Trailed through	A movement through a set of points in the <i>trailing direction</i> , when the switches were not set for the movement. Unless the points are designed for this, damage will result as the wheelsets attempt to force open the closed switch.*

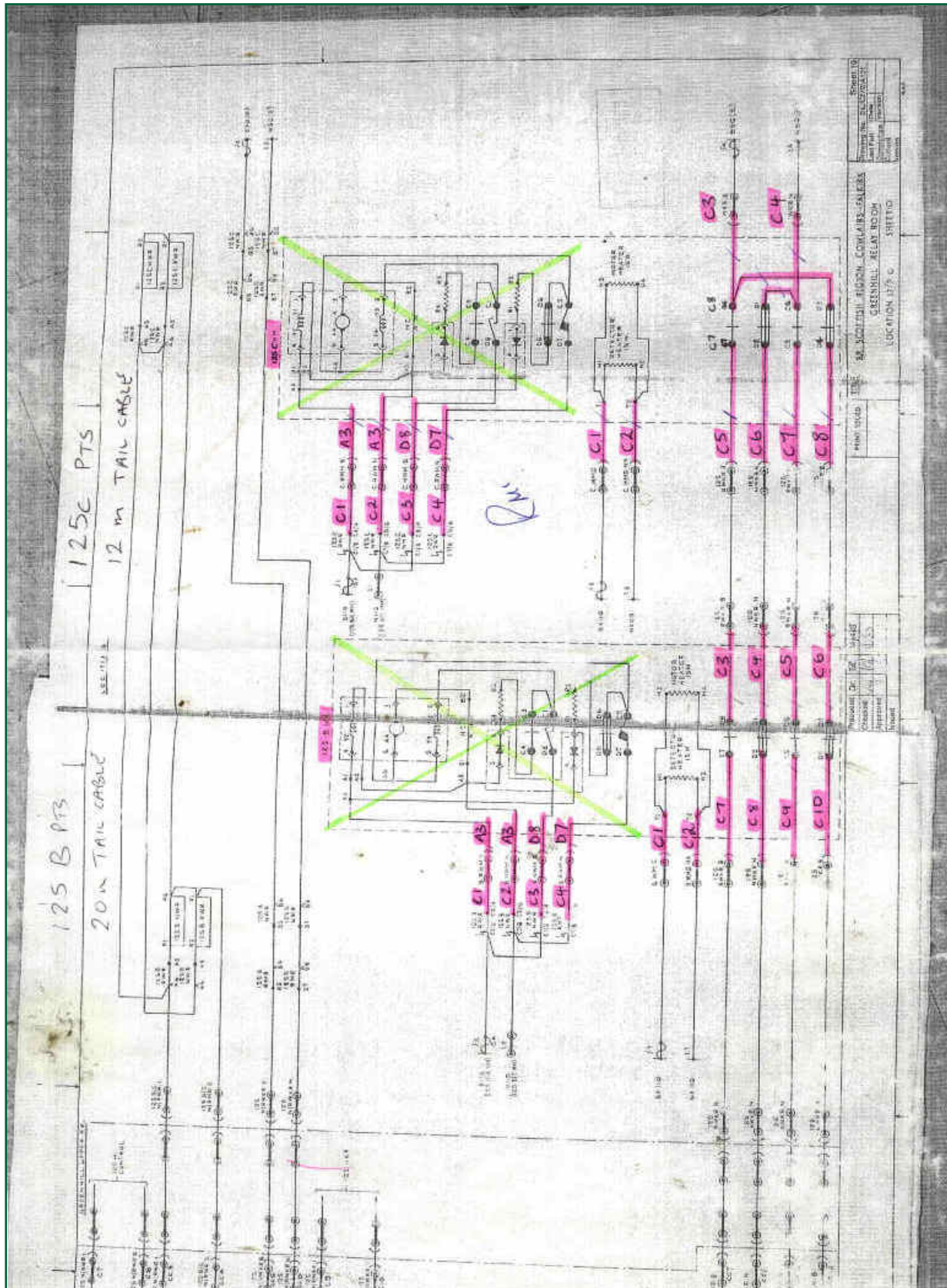
Trailing direction	The direction through a set of points (set of switches) where two routes converge in the normal direction of traffic.*
Validation	Demonstrating that a system meets its specified (eg safety) requirements.
Wire count	A visual examination to ensure that the correct number of wires are connected to each terminal as shown on the wiring diagram.
Works testing	The processes governing the testing of completely new signalling systems and existing systems where the design has been changed.
Wrongside signalling failure	A failure that causes a piece of equipment to cease functioning in such a way as to cause danger to the safety of the line.*

Appendix C - Key standards current at the time

GK/RT0209 ⁹	Testing and commissioning of signalling and operational telecommunications systems
NR/SP/SIG/11231	Signalling Maintenance Testing Handbook
NR/SP/SIG/11221	Signalling Works Testing Handbook
NR/GN/SIG/11600	Signalling and operational telecommunications design: technical guidance
NR/GN/SIG/11701	Signalling design: production guidance
NR/GN/SIG/11210	Signalling installation
NR/SP/CTM/012	Competence and training in signal engineering
NR/SP/SIG/10160	Signal engineering: licensing scheme – confirmation of competence

⁹ Available from www.rgsonline.co.uk

Appendix D - The drawing used to pre-wire 125B and 125C points



Appendix E - The RAIB's analysis of the data covering the out of correspondence test of 125 points

Time (hrs)	What happened	Comment
04:47:30	Points called normal	
04:47:33	Normal detection obtained	Points in correct position for the start of the out of correspondence test. Following this, all three point ends would be isolated if the test was done correctly. The time elapsed of 1 min 32 s before the start of the test is consistent with this.
Stage 1	125A, 125B, 125C isolated	
04:49:05	Points called reverse	Requirement of the test
04:50:22	Reverse detection obtained	This took 1 min 17 s indicating the points were manually operated. The time taken indicates all three ends were moved manually by two persons and suggests all three ends had been isolated as required.
04:51:18	Points called normal	This was possibly a spurious operation of the individual point switch.
04:51:48	Points called reverse	The individual point switch was operated back to reverse but the points were still in reverse as the reverse detection relay energised only 3 s later.
04:51:51	Reverse detection obtained	Indicates that the points were still reverse
04:52:04	Points called normal	Requirement of the test
04:53:05	Normal detection obtained	This took 1 min 1 s indicating the points were operated manually. The time taken indicates all three ends were moved manually. This suggests the completion of the first stage of the permutation table.
Stage 2	125A and 125B isolated	
04:55:12	Points called reverse	Requirement of the test
04:56:01	Reverse detection obtained	This part of the test requires two ends to be on manual and the 49 s from points called to detection obtained is probably consistent with this (two persons involved).
04:56:12	Points called normal	Requirement of the test
04:56:35	Normal detection obtained	This took 23 s which is achievable for manually operating two point ends with two persons. This suggests the completion of the second stage of the permutation table.
Stage 3	125A and 125C isolated	
04:57:29	Points called reverse	Requirement of the test
04:57:58	Reverse detection obtained	This part of the test requires two ends to be on manual and the 29 s from points called to detection obtained is probably consistent with this (two persons involved).

04:58:05	Points again called reverse	Suggests one of the isolated ends was mistakenly moved from reverse causing 125 RWR to energise.
04:58:16	Reverse detection obtained again	
04:58:25	Points called normal	Requirement of the test
04:58:49	Normal detection obtained	This part of the test requires two ends to be on manual and the 24 s from points called to detection obtained is probably consistent with this when two persons would have been used. This suggests the completion of the third stage of the permutation table.
Stage 4	125A isolated	
04:59:52	Points called reverse	Requirement of the test
05:00:12	Reverse detection obtained	This part of the test requires one end to be on manual and the 20 s from points called to detection obtained is probably consistent with this (manual operation by one person).
05:00:25	Points called normal	Requirement of the test
05:00:43	Normal detection obtained	This part of the test requires one end to be on manual and the 18 s from points called to detection obtained is probably consistent with this. This suggests the completion of the fourth stage of the permutation table.
Stage 5	125B and 125C isolated	
05:01:11	Points called reverse	Requirement of the test
05:01:31	Reverse detection obtained	This part of the test requires two ends to be on manual ('B' and 'C' on the switch diamonds; both operated by one person) and 20 s elapsed from points called to detection obtained. With the wiring fault, detection would have been obtained after manually operating just one point end (assuming the 'B' end was manually operated first). It is likely that this would have been the first occasion on which the fault could have been identified as the points would have been incorrectly shown in correspondence for 15 s.
05:01:46	Points called reverse again	This is likely to have occurred when 125C was manually operated causing 125 RWR to energise.
05:01:56	Reverse detection obtained again	This occurred after the second point end had been manually operated (probably 125C, with the crank handle being left in 125C ready for manual operation back to normal). Total elapsed time for the two point ends was 45 s.
05:02:07	Points called normal	Requirement of the test

05:02:49	Normal detection obtained	The 42 s from points called normal to detection obtained is probably consistent with the manual operation of two point ends. Given the time taken and that normal detection was only obtained once, the evidence suggests that 125C was manually operated first back to the normal position, followed by 125B (the handle would probably have been left in 125C from when it was operated reverse – see above). If 125B had been manually operated first, normal detection would have been obtained and then lost again when 125C was manually operated. Normal detection would only have then been obtained again when it was detected in the normal position. This suggests the completion of the fifth stage of the permutation table.
Stage 6	125B isolated	
05:03:11	Points called reverse	Requirement of the test
05:03:38	Reverse detection obtained	This part of the test requires one end to be on manual and 27 s elapsed from points called to detection obtained is probably consistent with this
05:03:46	Points called normal	Requirement of the test
05:04:08	Normal detection obtained	This part of the test requires one end to be on manual and the 22 s from points called to detection obtained is probably consistent with this. This suggests the completion of the sixth stage of the permutation table.
Stage 7	125C isolated	
05:04:33	Points called reverse	Requirement of the test
05:04:36	Reverse detection obtained	The fault condition would probably have been revealed here as it could be assumed that 125C was isolated at this point and still detected normal yet detection was obtained as though all three ends were on power and detected in reverse (only 3 s after being called reverse). The points would have shown in correspondence on the signaller's panel until 05:04:40.
05:04:40	Points called reverse again	This is probably when 125C started to be cranked towards the reverse position energising 125 RWR when detection was lost. The points would now (correctly) show out of correspondence.
05:04:52	Reverse detection obtained	This is probably when 125C completed being cranked to the reverse position and detection was obtained (correctly this time).
05:04:59	Points called normal	Requirement of the test

05:05:02	Normal detection obtained	The fault condition would probably have been revealed here as with 125C still isolated and detected reverse, detection was obtained as though all three ends were on power and detected in normal (only 3 s after being called normal). The points would incorrectly show in correspondence for 3 s.
05:05:05	Points called normal again, no detection	This is probably when 125C started to be cranked towards the normal position energising 125 NWR when detection was lost. The points would now (correctly) show out of correspondence.
05:05:13	Points called reverse again, no detection	Possibly a spurious operation of the individual point switch for 125 points. 125A and 125B ends would have moved reverse but there would have been no detection because 125C was part way across.
05:05:20	Points called normal again	Resumption of test; 125A and 125B move back to normal.
05:05:36	Normal detection obtained	This is probably when 125C completed being cranked to the normal position with all three point ends now being correctly in the normal position. The time elapsed from when this started at 05:05:05 suggests this process was interrupted. This suggests the completion of the seventh stage of the permutation table.
05:08:23 to 05:08:44	Two cycles of operation to reverse and back to normal	Carried out under power
05:08:44	End of testing	

Appendix F - The circuitry associated with 125 points

1. When a signaller sets a route over 125 points by pushing the entrance and exit buttons on the panel, the required position of the points is commanded by the interlocking in Greenhill relay room and by equipment in location case 17/2C (figure 10). The command to change the position of a set of points is known as points calling.



Figure 10: Location case 17/2C

2. There are *relays* in location case 17/2C which provide local commands to 125 points and which detect the position of the switch rails. The designation and function of these relays is in Table 3.

Relay name	Function	Usual state
125A NWR	Local command to call 125 points normal	Energised if 125A RWR is de-energised
125A RWR	Local command to call 125 points reverse	Energised if 125A NWR is de-energised
125 NWKR	Local detection relay	Energised when all 125 switch rails are normal
125 RWKR	Local detection relay	Energised when all 125 switch rails are reverse

Table 3: Relays associated with the control of 125 points

3. Each relay consists of a coil, an armature and a set of contacts. When a voltage is applied to the coil, an electro-magnetic field is set up in the soft iron core within the coil which attracts the armature to it. This action operates the set of contacts; some of which may be closed when the relay is de-energised and open when energised, whereas others may close when the relay is energised and open when de-energised. Contacts that are made when the relay is energised are known as front contacts and those that are broken when the relay is energised are known as back contacts.
4. The relays in table 3 belong to the BR specification 930 series of 'miniature' relays and operate on 50 volts direct current. They are each enclosed in a clear plastic case to provide protection from the elements. The complete assembly plugs into a plugboard to which the various connections are wired. The relay is held in place by a retaining clip. Figure 11 shows the relays in table 2 in position in location case 17/2C.

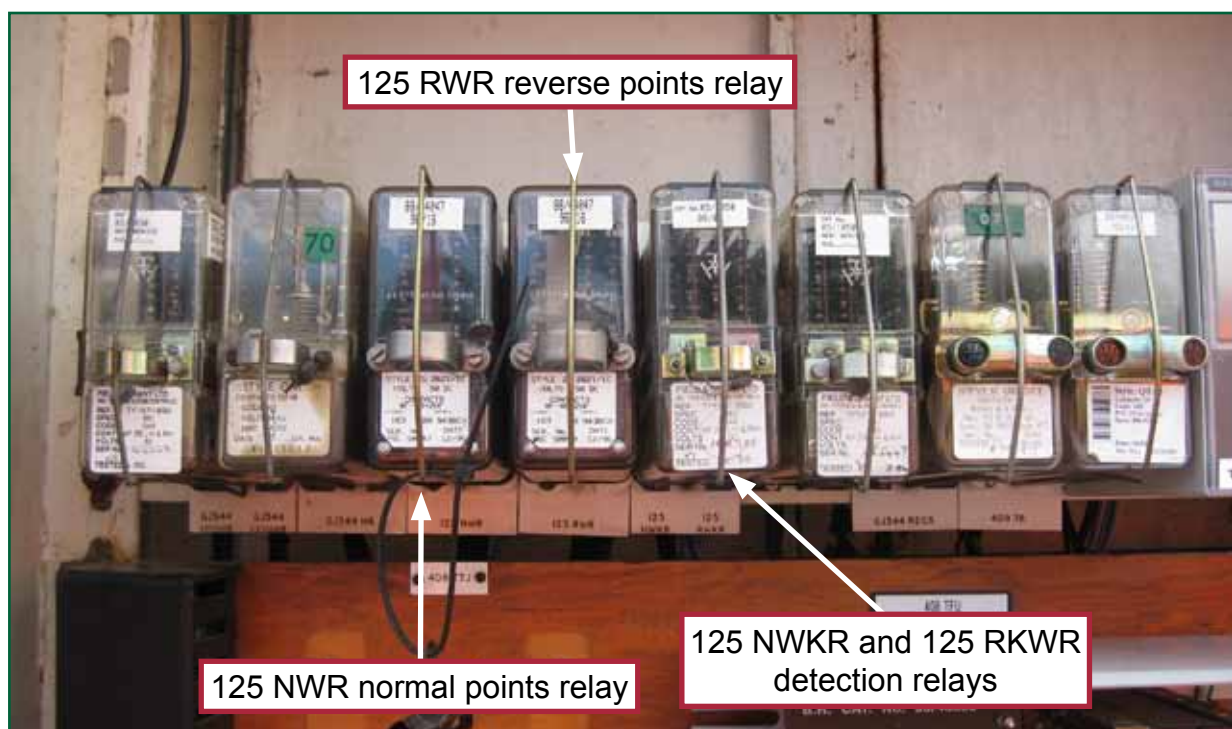


Figure 11: The relays associated with the control of 125 points

5. The two detection relays, 125 NWKR and 125 RWKR, are both contained in a single plastic case and each has six front contacts and two back contacts. They are biased relays which only energise when direct current is flowing in one direction through their coil.
6. Figure 12 shows a simplified diagram of the detection circuit associated with 125 points. There are two detection contacts for each point end position to allow the circuits to be *double cut*. They are contained within each point machine (figure 13) and are wired in series between each of the 125 point ends. Each contact has to be closed, either normal or reverse, in order to energise the appropriate detection relay. This should only occur when all the associated switch rails are in the correct position.

7. On an HW type point machine, two metal “H” shaped pieces are fixed to a central rocker (figure 14). This rocker moves from one side to the other depending upon whether the point ends are detected in normal or reverse. When detection is obtained, the ‘H’ shaped pieces touch fixed contact springs. The wiring for the detection circuits is connected to these contact springs via terminals, with one wire in and one wire out for each detection contact.
8. If detection is lost without a command to move the points from the interlocking, a back contact on the appropriate detection relay energises the respective points calling relay to attempt to drive the points back to the required position to regain detection.

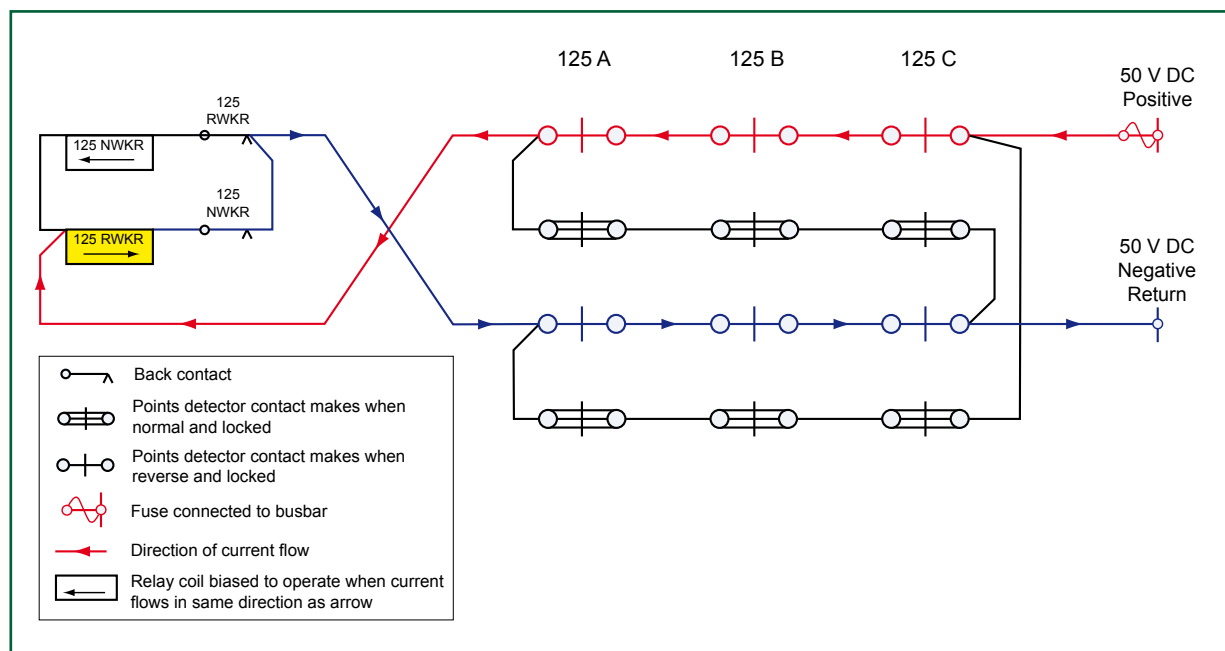


Figure 12: Simplified diagram of the detection circuit associated with 125 points (showing points detected and locked reverse)

9. The circuit containing the 125 detection relays uses only two wires to connect them to the detection contacts in the point machines and is therefore known as a two wire detection circuit. Such a circuit is a pole changing circuit as the polarity (the direction of the electric current) is changed depending on which detection contacts are made which reduces the number of wires that would otherwise be required. The circuit requires wire straps to be fitted to the terminals inside 125C and 125A point machines (figure 12) to enable it to work.
10. The interlocking knows the actual position of the points as detected by 125 NWKR and RWKR using other circuitry. Detection is indicated to the signaller by a white light on the panel. The failure of detection (out of correspondence) is indicated by a separate flashing white light (figure 9 - see page 28).
11. Each point machine is connected by two multi-core tail cables: one containing ten cores and the other containing four cores. The ten core cable contains the cores that feed the detection circuit and return it to the detection relays at the location case. The four core cable contains the feed to the motor that drives the machine.

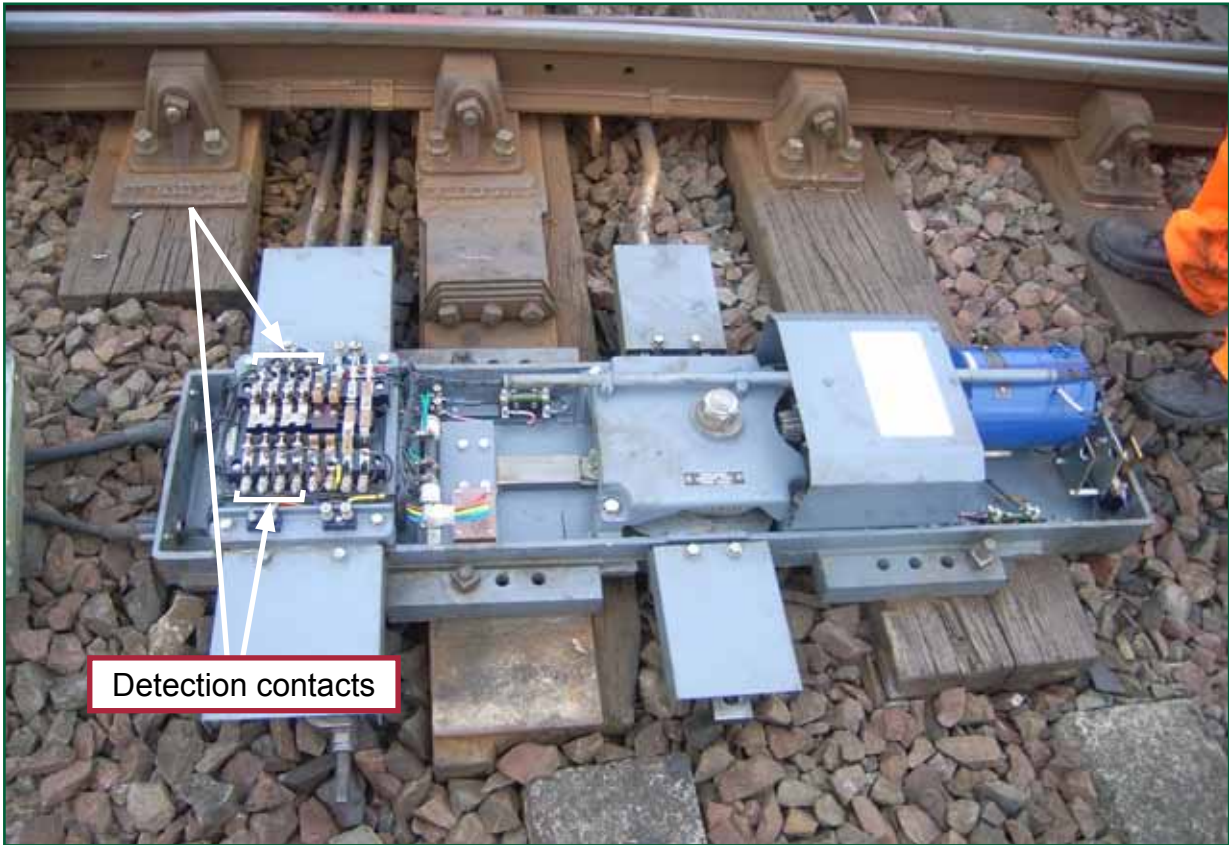


Figure 13: An HW2000 point machine with the cover removed

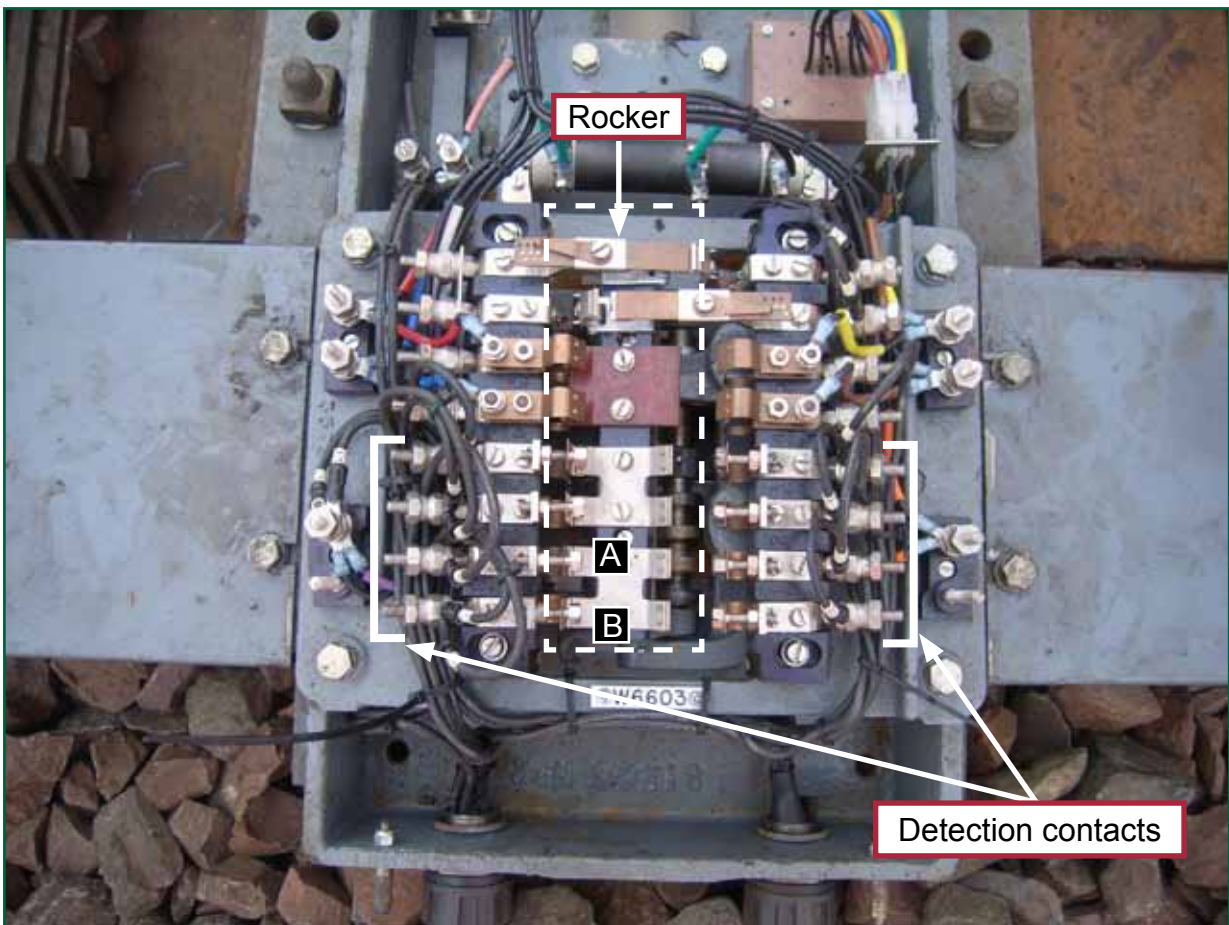


Figure 14: HW2000 point machine detection contacts

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