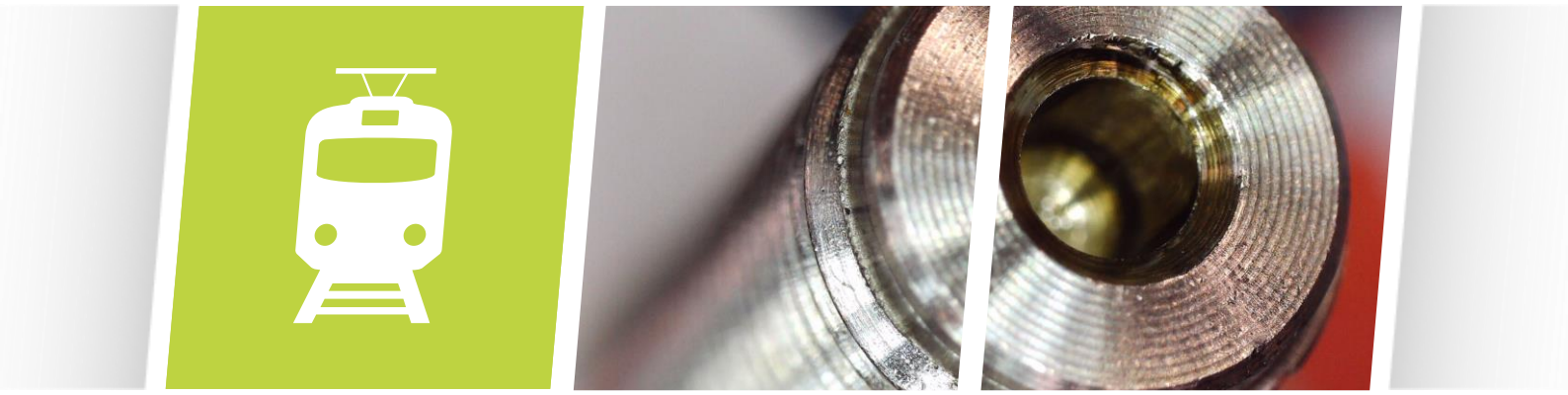
Norwegian Safety Investigation Authority



Issued December 2022

# REPORT RAIL 2022/08

## *Faulty interlocking system at Jar metro station on the Kolsås line, 27 November 2021*

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*The Norwegian Safety Investigation Authority (NSIA) has compiled this report for the sole purpose of improving railway safety.*

*The object of the NSIA's investigations is to clarify the sequence of events and causal factors, elucidate matters deemed to be important to the prevention of accidents and serious incidents, and to issue safety recommendations if relevant. It is not the task of the NSIA to apportion blame or liability.*

*This report should not be used for purposes other than improvement of railway safety.*

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Photo: Siemens Mobility Ltd.

This report has been translated into English and published by the NSIA to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report for reference.

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# Summary

At 07:56 on Saturday 27 November 2021, Sporveien T-banen AS's traffic controller observed that train reporting no 1316, an SL95 type tram, appeared in the traffic controller's system as being 'Lost at track'. The traffic controller initiated troubleshooting procedures and received confirmation that the subsequent train no 303, an MX metro train, was also presented as not occupying the track section. Track circuit 839 covers the track section along the platform for incoming metro trains at Jar station.

Personnel from Sporveien checked the situation in the signal box and found that the track circuit relay did not open as intended when track circuit 839 was short-circuited. After removing and putting the relay back into its holder, it worked in the normal manner. The relay was nonetheless replaced as a consequence of the incident and before resuming normal operations. The track relay had been overhauled at the manufacturer and supplier's in May 2021 and had been in operation in the system for less than six months.

The situation had no repercussions in this case, but train detection failure means that the signalling system cannot detect trains, which increases the risk of vehicle collisions.

The NSIA procured tests of the relay by the UK manufacturer Siemens Mobility Limited as well as detailed measurements and examinations by Kongsberg Aviation Maintenance Services and the Norwegian Armed Forces Laboratory Services.

The NSIA has been unable to come to a definitive conclusion as to why the relay did not open when the track circuit was short-circuited by the vehicles, but it is likely that vane rotation was prevented by small metal fragments found in the bearings of the relay's vane.

It has not been possible to determine how the metal fragments entered the bearings. The relay is a sealed unit that is only opened at the factory. A possible explanation comes from the way these bearings were manufactured or stored at the factory, or from improper cleaning during reassembly after being overhauled.

The NSIA does not issue any safety recommendations following the investigation. Siemens Mobility has shortly after the investigation of the relay changed their method for cleaning the bearings in the assembly process.

# About the investigation

## Decision to investigate

On 29 November 2021, the Norwegian Safety Investigation Authority (NSIA) was notified by Sporveien T-banen AS of an incident which had occurred on 27 November 2021 where track circuit 839 had failed to indicate track occupancy[1] with a vehicle occupying the relevant track section.

The decision to conduct a safety investigation was based on the seriousness of the incident with reference to Section 11 of the Act of 3 June 2005 No 34 on Notification, Reporting and Investigation of Railway Accidents and Railway Incidents etc. (Railway Investigation Act).

The parties involved were informed on 3 December 2021 of the NSIA having initiated an investigation. The European Union Agency for Railways (ERA) was informed on the same date.

## Purpose

The NSIA is the investigating authority for railway accidents and railway incidents. Pursuant to Section 3 of the Railway Investigation Act, the investigating authority shall clarify the sequence of events and causal factors, identify factors of importance to the prevention of railway accidents and issue an investigation report.

It is not the investigating authority's task to apportion blame or liability under criminal or civil law. The investigations shall be conducted independently of other investigations or inquiries wholly or partly conducted for such purposes.

## Organisation, scope and delimitation

The investigation mandate and how the investigation was to be organised were decided at the start-up meeting. The investigation was carried out as project work under the leadership of the Investigator in charge. The investigation owner is the director of the NSIA's rail department.

The NSIA decides the scope of the investigation and how it is to be conducted. When making the decision, account is taken of what lessons can be learnt from the investigation with a view to improving safety, the degree of severity of the accident or incident, its bearing on railway safety in general and whether it forms part of a series of accidents or incidents.

In this specific investigation, the NSIA has focused on possible reasons why the track section was presented as unoccupied and why the track relay remained closed, despite short-circuiting of the track circuit or removal of the driving voltage for the relay.

## The investigation process

When an investigation is initiated, the parties involved are notified by letter and via the NSIA's website. Before a final report is issued, a draft report is sent to the parties so that they are informed of the content and can submit comments. In some cases, this will lead to further investigation for clarification purposes or to verify new elements that are brought to the NSIA's attention. NSIA decides which comments that will be implemented in the final report.

The final investigation report is submitted to the Ministry of Transport, which takes necessary measures to ensure that due consideration is given to the safety recommendations, cf. Section 16

[1] *Occupation – detection of the presence of a vehicle or other technical device on a track section.*

of the Regulations of 31 March 2006 No 378 on Public Investigations of Railway Accidents and Serious Railway Incidents etc. (Railway Investigation Regulations).

## Information sources and methods

- Information systems at Sporveien T-banen AS and Sporveien AS
- Internal rules, governing documents and instructions
- Applicable legislation and regulations
- Interviews
- Inspection of the incident site
- Examinations conducted by the NSIA, supported by the UK Rail Accident Investigation Branch (RAIB) and commissioned expertise.
- The NSIA's framework for systematic safety investigations and pertaining methods.

## Use of the report

This report should not be used for purposes other than improvement of railway safety.

Source references shall be included when reproducing any of the content of the report.

# 1. Factual information

# 1. Factual information

## 1.1 Data relating to the incident

*Table 1: About the incident*

| | |
|---|---|
| **Track incorrectly presented as unoccupied** | |
| **Time of incident:** | Saturday 27 November 2021 at 07:56 |
| **Location:** | Jar station in Bærum municipality |
| **Train number:** | 1316 |
| **Rolling stock involved:** | SL95 |
| **Infrastructure manager and railway undertaking:** | Sporveien T-banen AS |

## 1.2 Sequence of events

At 07:56 on Saturday 27 November 2021, Sporveien T-banen AS's traffic controller observed that train no 1316, an SL95 type tram, was presented in the traffic control system as being 'Lost at track'. The traffic controller completed the established troubleshooting procedures, and received confirmation that the subsequent train no 303, an MX metro train, was also presented as not occupying the track section. Track circuit 839 covers the track section along the platform for incoming metro trains at Jar station (Figure 1).

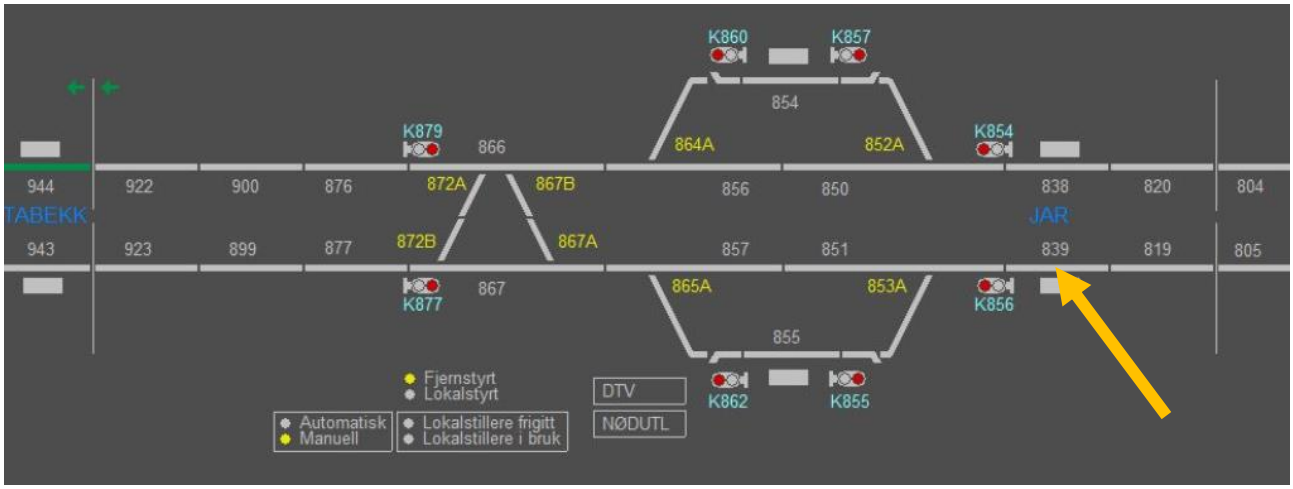


*Figure 1: Schematic track diagram showing track sections at Jar station (the relevant track section is marked). Source: Sporveien T-banen AS*

The traffic controller deployed a signal engineer to troubleshoot the scene, while also deactivating the automatic system at Jar in order to control train movements manually.

Personnel from Sporveien T-banen AS checked the situation in the relay room and found that the track circuit relay did not open as expected when track circuit 839 was short-circuited. After removing and putting the relay back into its holder, it worked in the normal manner. The relay was nonetheless replaced as a consequence of the incident, before resuming normal operations.

The situation had no consequences in this case, but track detection failure means that the signalling system does not work, which increases the risk of vehicle collisions.

## 1.3 Work in the vicinity

No work had been carried out beforehand and no work was in progress on Sporveien T-banen's signalling system when the incident occurred.

## 1.4 Injuries and damage

### 1.4.1 PERSONAL INJURIES

Nobody was injured as a consequence of the incident.

### 1.4.2 DAMAGE TO THE ROLLING STOCK INVOLVED

No rolling stock was damaged as a consequence of the incident.

### 1.4.3 DAMAGE TO INFRASTRUCTURE

No infrastructure was damaged as a consequence of the incident.

## 1.5 Weather

On Saturday 27 November 2021, temperatures of between -3.8 and -2.1 degrees Celsius were recorded at the Norwegian Meteorological Institute's weather station at Blindern in Oslo. No rainfall or snow was reported on the day or during the days immediately preceding the incident.

## 1.6 Parties involved

### 1.6.1 SPORVEIEN T-BANEN AS

Sporveien T-banen AS (Sporveien T-banen) operates and provides all metro line services in Oslo and Viken. The company holds a licence from the Norwegian Railway Authority to conduct infrastructure operation, traffic management and rail transport services. The workshop and infrastructure, organised by the parent company Sporveien AS, are covered by Sporveien T-banen's operating licence.

Sporveien T-banen operates in accordance with an agreement with the administration company Ruter AS, under which Ruter AS issues timetables, while Sporveien T-banen plans and delivers the transport services. Sporveien T-banen operates five metro lines in Oslo, of which two extend into Bærum municipality in Viken county. At year-end 2021, Sporveien T-banen's workforce counted 596 employees.

### 1.6.2 SPORVEIEN AS

Sporveien AS (Sporveien) owns Sporveien T-banen. In addition, Sporveien supplies development and maintenance services to its subsidiary Sporveien T-banen.

Sporveien's infrastructure and project section is responsible for the maintenance, development and management of the group's properties and tram/metro infrastructure, including stations, tunnels, buildings and railway tracks. The entity employs a staff of approximately 370 employees, divided between Tøyen, Etterstad, Majorstuen, Grefsen and Holtet.

### 1.6.3 SIEMENS MOBILITY LTD.

Siemens Mobility Limited supplied the signalling system used at Jar station, and manufactured the relay involved in the incident. The factory is located in Chippenham in the UK and manufactures and maintains track relays.

## 1.7 Examination of rolling stock

Given that the fault did not depend on any individual vehicle or vehicle type passing through the track section, the NSIA has not conducted any technical examination of the rolling stock that passed through Jar station.

None of the rolling stock involved had reported issues on other track sections. Therefore, previous experience of sand isolating the wheels from the track circuits was not considered relevant to this investigation.

## 1.8 Traffic control and signalling system

The metro in Oslo has a fully monitored signalling system controlled by a traffic controller, permission to proceed is primarily received as an indication in the driver's cab. The cab signalling is continually updated by means of electrical signals transmitted through the track and received by antennas on board the train. Permitted speeds depend on track geometry and distance to the preceding train. The track is therefore divided into a number of track sections covered by track circuits detecting train positions. The train positions are transmitted to the signalling system which determines the speed code to be issued to the trains.

Correct train detection is therefore essential to ensure safe operation. Sporveien T-banen has various options in place to identify lack of train detection. The traffic management system is normally operated automatically, whereby the trains follow pre-planned routes and the traffic controllers can monitor this on their screens. If a track circuit fails to detect a train on the track section, the train can no longer be identified by its train number in the traffic controller's track diagram or in the system. The traffic controller will therefore notice this within a relatively short space of time. If that happens, the traffic controller will act in accordance with established guidelines for handling such situations. The procedures were followed as intended during the incident at Jar.

## 1.9 Inspection and observation of the relay's fault condition

On 20 January 2022, the NSIA inspected the signal box at Jar station. The signal engineer who troubleshot the system on the day of the incident was present during the inspection, in addition to signal engineers and safety staff representatives from Sporveien T-banen. During the inspection, the NSIA was given a demonstration of the system and supplied with relay and infrastructure documentation. The sequence of events on the day of the incident was reviewed and the troubleshooting activities were described and demonstrated. The NSIA relies on the description given by Sporveien personnel of their observations and troubleshooting of the system:

- The track phase supply of the relay was disconnected to check the opening and closing of the relay, but the relay did not open.
- Measured the voltage over the track phase that had been removed (0.03 V).
- Checked voltage of track phase (2.54 V) and local phase (227.08 V) without any break in the circuit.
- Disconnected local phase only without the relay opening and measured the voltage (0.63 V).

- Disconnected both voltages without the relay opening.
- Reapplied the voltage and measured all phases against earth (no abnormal values).
- Checked earth fault indication in the relay room.
- The track relay was physically removed, which caused it to open. It was put back into place and the relay closed. The track phase was removed and the relay opened in the normal manner.
- The relay was then replaced with another relay. The track and local phases were disconnected and the relay removed, so that the track section was shown as occupied while a new relay was being fetched.
- Once the new relay had been installed, the following track circuit values were measured:
    - Short-circuit current: 3.5 A
    - Draw rate of relay during normal operation: 290 mA
    - Fall shunt: 0.6 ohm
    - Drag shunt: > 1 ohm

The signal technician's visual observations and description suggest that, at the time of the incident, the relay remained closed when it should have opened. This tallies with observations made by train drivers and traffic controllers in the ATP system as well as what was indicated by the traffic management system. In order to simulate the passage of trains or lack of current supply from the local network, the fuses for these phases were deactivated. The magnetic field should thereby no longer be present and the relay should have opened by force of gravity. The relay did not open until it was physically removed from its base.

## 1.10 Examination of the VT1 relay

### 1.10.1 ABOUT THE RELAY

The relay involved in the incident at Jar was of the type Westinghouse Rail Systems Ltd Style VT1-6F-4B with serial number E02410989, manufactured by Siemens Mobility Ltd (Figure 2).

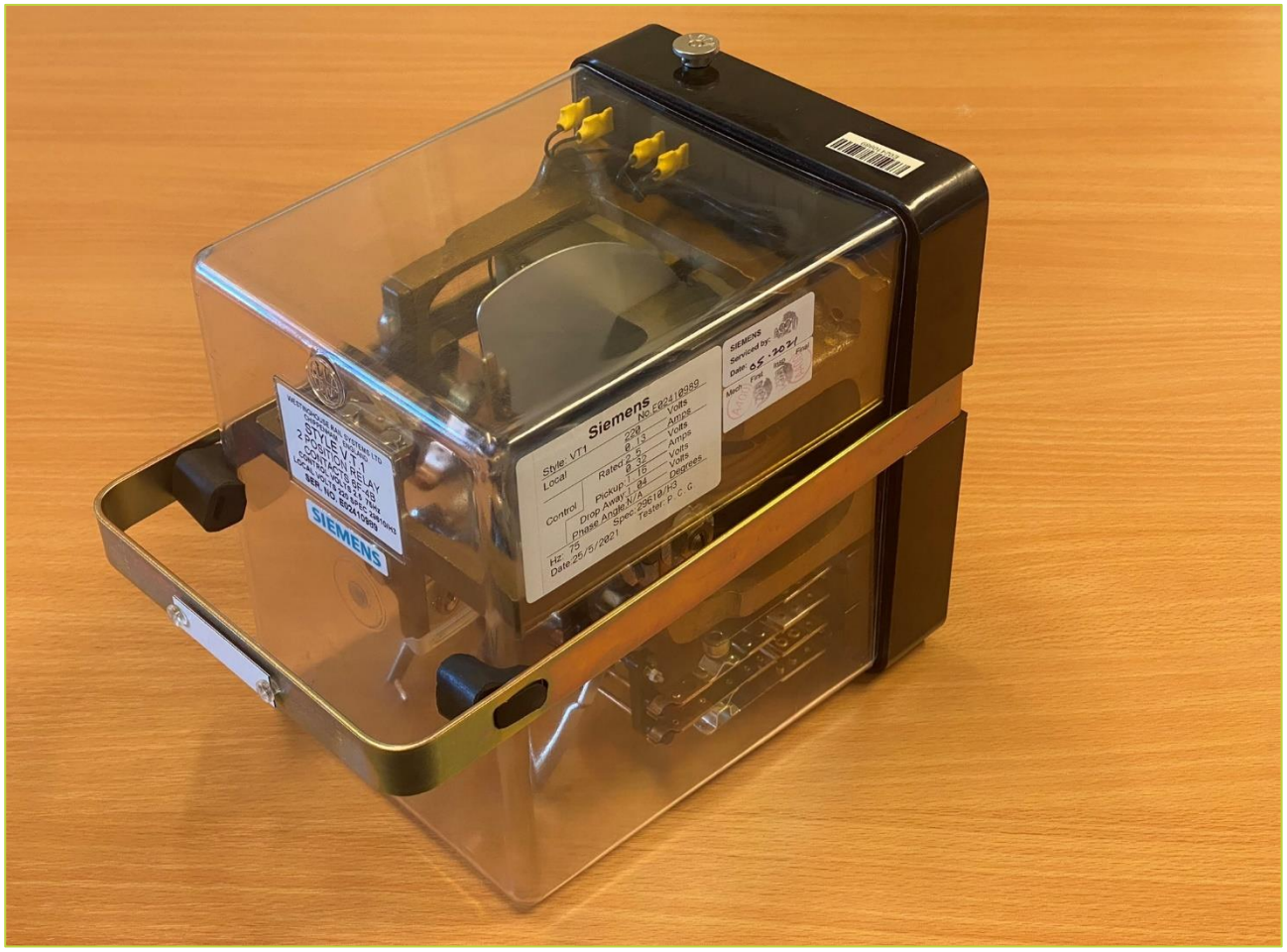


*Figure 2: VT1-6F-4B relay. Photo: NSIA*

This type of relay works by rotating a vane through a magnetic field created by a coil supplied from the electricity grid (local phase) and a coil supplied from the track circuit (track phase). The relay is opened by the force of gravity when the current feed from either of these sources is interrupted. The rotary movement of the vane is converted into linear movement by cranks and links and transmitted to contact assemblies. The contacts are coated with a special alloy to prevent contact welding if the design current is exceeded. Previous tests by Siemens Mobility with a view to further development and quality assurance of the relay type have shown that, in order for these contact points to weld together, the temperature would have to be so high that other components would melt and become deformed before it happened. The relay is encased and sealed, and is not opened by its users. It is mounted in a base, which is then connected to the relevant contact points used in the system.

The relay had been overhauled by the UK manufacturer and supplier, Siemens Mobility in Chippenham, on 25 May 2021, and had been installed in the system at Jar on 17 June 2021. On the day of the incident, the relay had thus been in use for just under six months, and according to the NSIA's estimates, it had been subject to approximately 20,000 movements. Sporveien T-banen's governing document IE-TB0000-300-AC-103 contains a requirement for such relays to be overhauled after eight years of operation, after which they may be stored for a maximum of three years before they are put back into operation. In addition, track sections and circuits also undergo periodic inspections.

According to Siemens Mobility, the relays have an estimated life of 10 years or 1 million movements.

The VT1 relay is a recognised and common type of relay for track sections. Westinghouse Brake and Signal Company developed and started to manufacture this type of relay in the 1950s, and it is still being produced today. VT1 relays are supplied in different voltage configurations for use on different railway systems around the globe. Today, these relays are manufactured and maintained by Siemens Mobility, which builds and maintains between 500 and 700 relays a year. According to Siemens, mean time between failures (MTBF), based on two sources of failure, is 2,557,544 and 6,666,666,667 hours, respectively.

Production, maintenance and inspection of the relays are carried out by a handful of personnel with extensive experience in the maintenance of the various types of VT1 relays.

Once the relay is ready for dispatch to the customer, it is packed in a purpose-built box, equipped with an impact detection device. Sporveien stores the relays in these boxes when they are not installed in the signalling system. The impact detectors are checked before the relays are removed from their boxes for installation. If the impact detector has been triggered, the relay is returned to the factory for inspection and overhaul.

The NSIA has stored the relay in the same type of box ever since it was taken in possession for inspection purposes.

### 1.10.2 EXAMINATION OF THE VT1 RELAY AT SIEMENS MOBILITY IN CHIPPENHAM

On 16 March 2022, the NSIA carried out tests of the relay at Siemens Mobility Limited in Chippenham to determine possible reasons why the relay did not open as intended. The purpose of the examination was to verify the relay's functionality, document any faults and understand how production and testing of the relay were performed.

The relay was transported as hand luggage in its original box. Prior to the examinations at Siemens's, the NSIA had only inspected the relay visually, without disassembling it. The relay has been handled with care when removed from the box.

The tests were conducted in cooperation with the UK Rail Accident Investigation Branch (RAIB). The RAIB also took part in planning the tests and lent expertise to the investigation before and after the tests in Chippenham.

At the time of the tests, Siemens Mobility gave a demonstration of its system for maintenance of such relays, and the staff ran through the whole maintenance process. A presentation was given of stockkeeping, procedures for maintenance of individual components and potential scrapping of components. The staff demonstrated how relays are disassembled and reassembled.

Siemens Mobility gave the NSIA a demonstration of assembly and testing and inspection of a VT1 relay. The sleeves used as bearings for the pivot ends are stored in a box next to the workshop. The sleeves are supplied by a subcontractor and made to the correct bore diameter. To prevent any dirt from entering the relay when it is assembled, the sleeves are purged with pressurised air before they are mounted in the relay together with the pivoted vane. The premises were clean, and both staff and guests were required to wear coveralls.

### 1.10.2.1 Test programme

A programme for technical examinations of the relay had been established in advance. Representatives of the NSIA and RAIB participated in, documented, and monitored all parts of the examinations. The programme comprised:

- Presentation and discussion of the issue – visual inspection of the relay.
- Testing the relay in a test bench – using the values measured at Jar on the day of the incident as well as limit values in the specifications for the relay.
- Test-bench comparison of the relay with a corresponding relay.
- Various forms of test-bench manipulation to trigger possible faults.
- Final testing and inspection – as would occur before delivery to a customer.
- Checking all tolerances, weights and clearance gaps.
- Dismantling of the relay for inspection of all parts.

### 1.10.2.2 Results of the tests

The tests conducted before the relay was disassembled showed that it worked as intended without any faults. There were no signs of locking, obstruction or braking that could explain why the relay did not open as intended on the day of the incident. The relay opened by the force of gravity and has a minimum norm weight of 9 grams. In this particular relay, the weight was 14 grams. The NSIA tried various forms of manipulation of the relay to test different working hypotheses, but it was not possible to reproduce the fault with the vane rotated to the closed position as it would have been on the day of the incident.

The examinations resulted in two main findings:

1. When the relay was checked in relation to the specifications for final testing and inspection, the vane was found to have been displaced laterally by 1/1,000 inch.
2. When the relay was disassembled, particles were found inside the vane bearings (Figure 6, Figure 8).

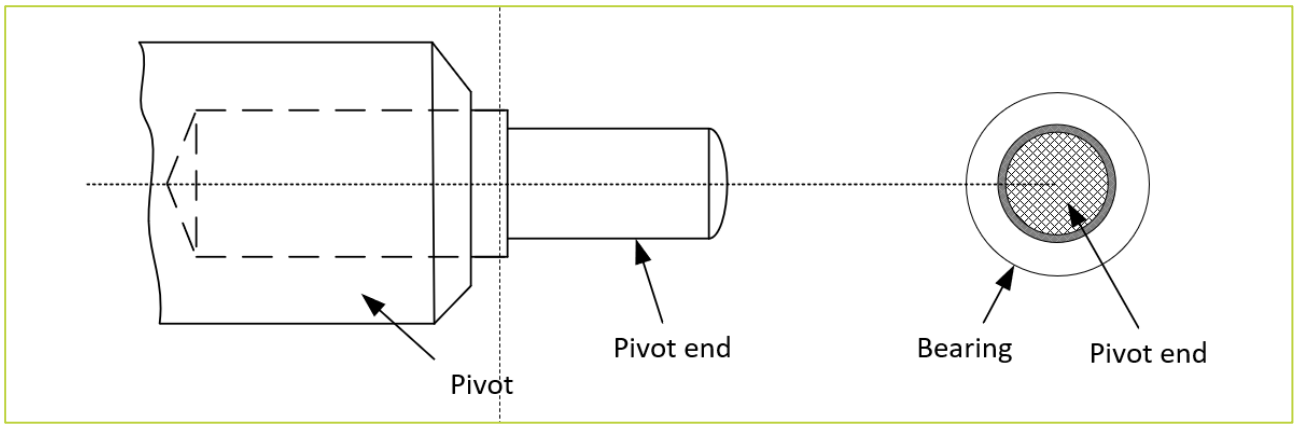


*Figure 3: Schematic drawing of pivot and bearing. Illustration: NSIA*


*Figure 4: Comparable relay mounted on top of test bench. The relay involved in the incident can be seen on the left-hand side of the worktop. Photo: NSIA*

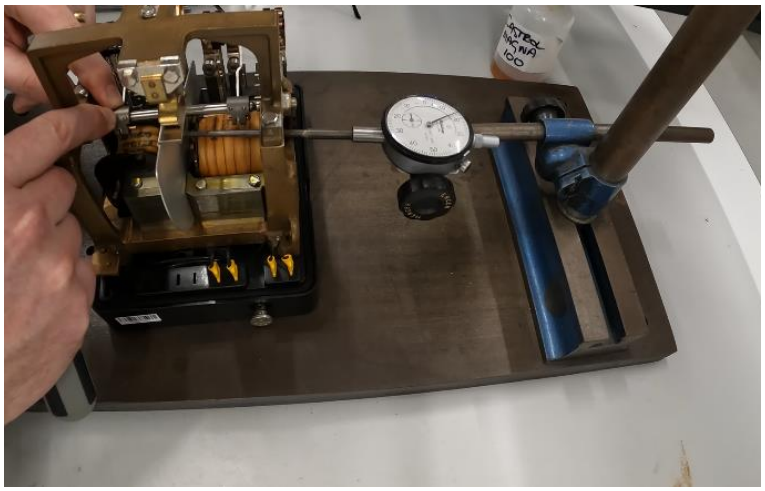

*Figure 5: Measuring lateral vane clearance. Photo: NSIA*

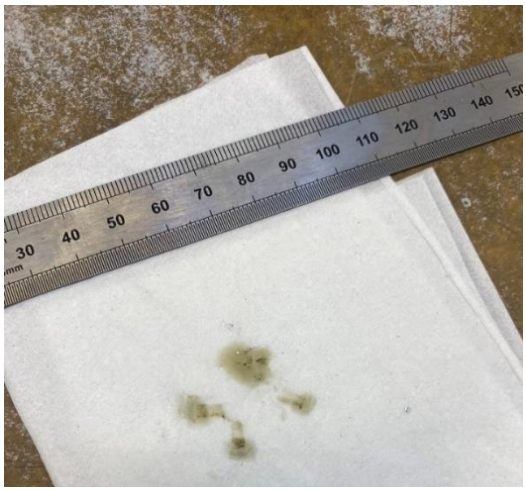


*Figure 6: Wiped-off material from the vane. Photo: NSIA*

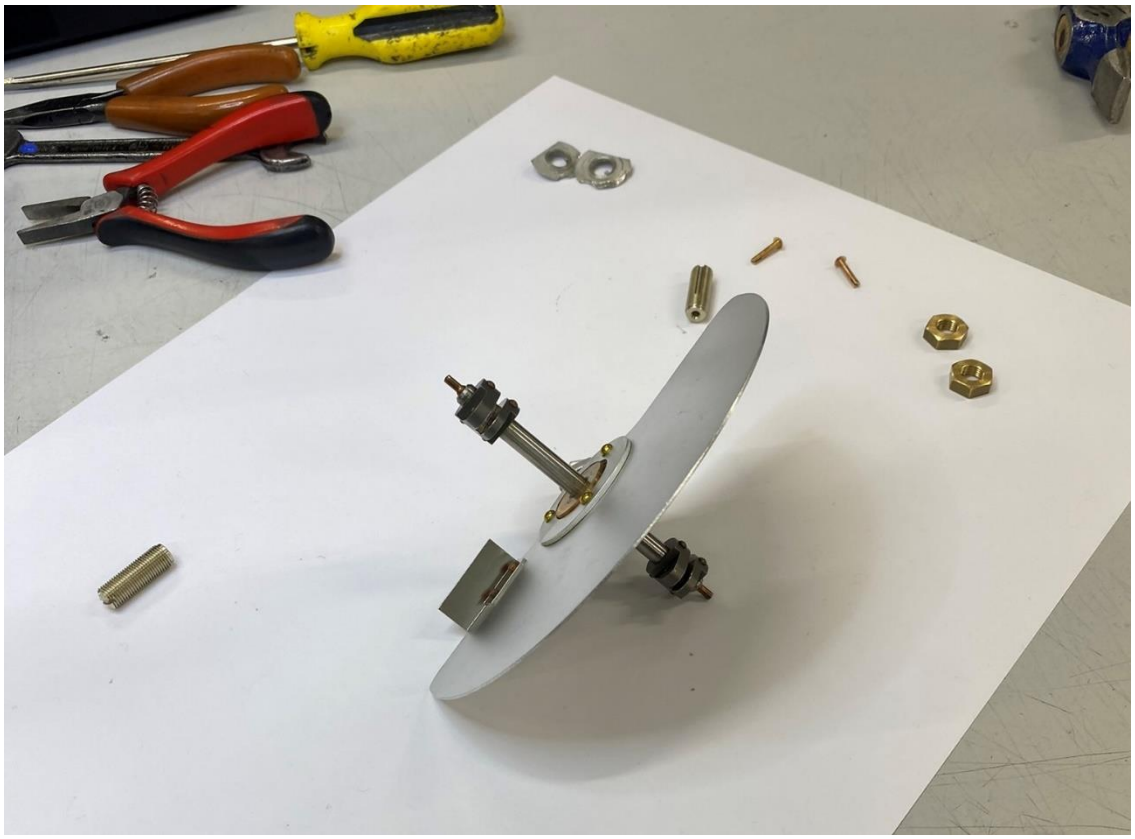

*Figure 7: Vane. Photo: NSIA*

The wiped-off material from the pivot ends and bearings was examined under a microscope that Siemens Mobility had access to, and then brought back to the NSIA for further examination.

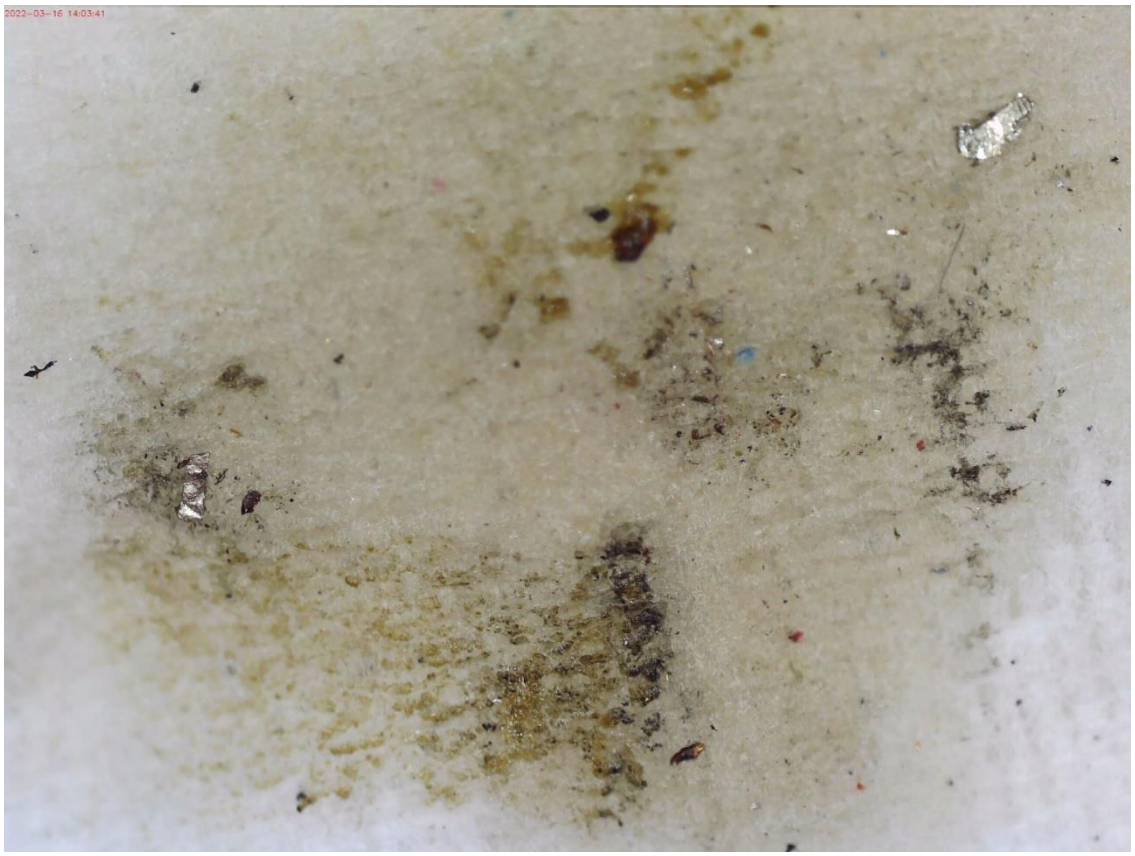


*Figure 8: Fragments found on the pivot ends using a microscope. Photo: Siemens Mobility Ltd.*

### 1.10.3 EXAMINATION BY THE NORWEGIAN ARMED FORCES LABORATORY SERVICES (FOLAT) OF FRAGMENTS FOUND ON THE VANE

Given that the bearings were found to contain fragments, the NSIA requested further examinations of the fragments by the Norwegian Armed Forces Laboratory Services. These examinations enabled documentation of fragment sizes and alloys. The particles were described as consisting of a brass alloy, using energy-dispersive X-ray spectroscopy (EDS). The NSIA did not observe any wear on the pivot ends or bearings that could explain the fragments.

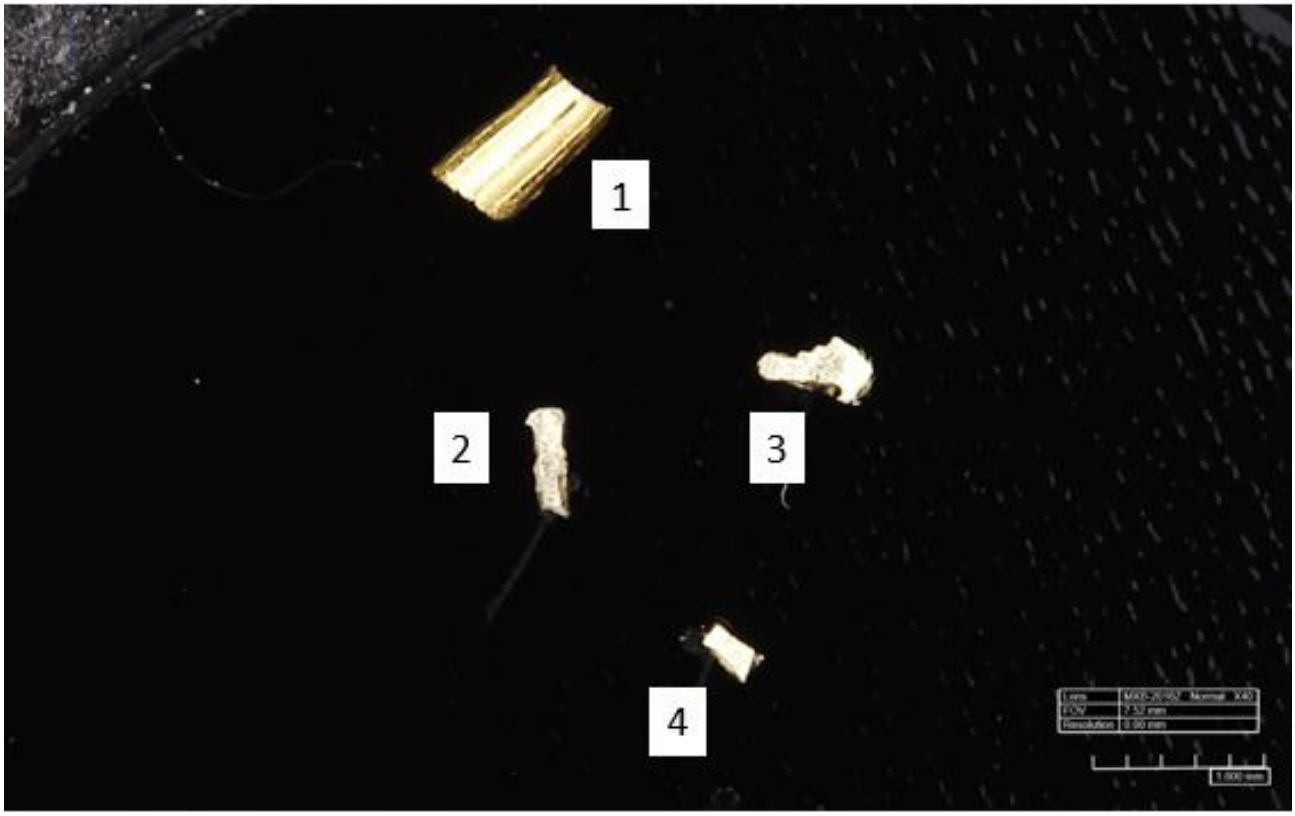


*Figure 9: Overview of the fragments found on the pivot ends. Fragment sizes are stated in Table 4. Photo: FOLAT*

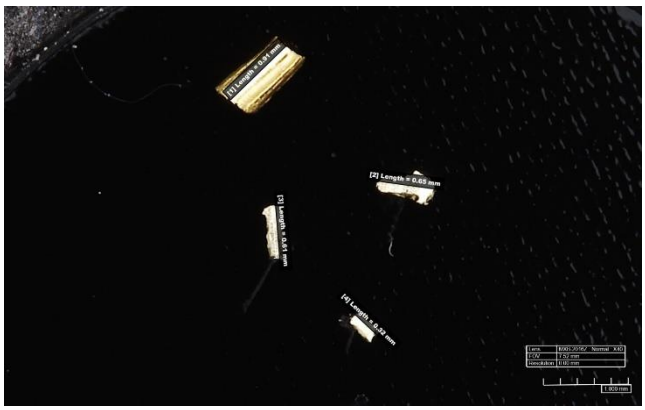

*Figure 10: Fragments marked with length. Photo: FOLAT*

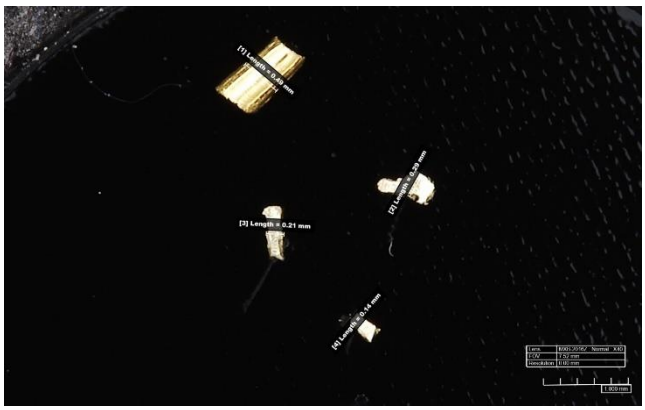

*Figure 11: Fragments marked with width. Photo: FOLAT*

### 1.10.4 EXAMINATIONS OF THE RELAY BY KONGSBERG AVIATION MAINTENANCE SERVICES (KAMS)

The NSIA commissioned Kongsberg Aviation Maintenance Services to measure the diameters of the pivot ends and bearings. The company has special measuring equipment for this purpose. The diameters were measured in three places on the vane and inside the bearings. The diameters

measured are stated in inches (imp) as this is the unit of measurement used on the original drawings. The results are shown in Table 2.

*Table 2: Overview of measured bearing bore and pivot end diameters. Table: NSIA*

| | Right-hand bearing, bore diameter | Left-hand bearing, bore diameter | Vane, right-hand pivot end diameter | Vane, left-hand pivot end diameter | Clearance bearing/ pivot end, right-hand side | Clearance bearing/ pivot end, left-hand side |
|---|---|---|---|---|---|---|
| At the top/tip | 0.0998 | 0.0998 | 0.0929 | 0.0929 | 0.0069 | 0.0069 |
| Centre | 0.0992 | 0.0992 | 0.0927 | 0.0928 | 0.0065 | 0.0064 |
| At the bottom/ closest to vane | 0.0986 | 0.0987 | 0.0926 | 0.0926 | 0.0060 | 0.0061 |

Table 2 shows bearing bore and pivot end diameters and the calculated clearance between the pivot ends and bearings in each case. The lowest calculated clearance was 0.006 inches. The lowest calculated clearance was used as the limit value for fragment size, shown in Table 4.

Table 3 shows tolerance limits for pivot ends and bearings. All measured variants met these requirements.

*Table 3: Tolerance limits for clearance between pivot ends and bearings. Source: Siemens Mobility Ltd. Drawings A51071 and A15012*

| | Bearing | Vane |
|---|---|---|
| Maximum | 0.100 | 0.0935 |
| Minimum | 0.098 | 0.0925 |

*Table 4: Overview of fragment sizes, highlighted in red where they exceed the clearance between bearings and pivot ends. Table: NSIA*

| Fragments found in the bearings, ref. Figure 9 | Width (imp) | Length (imp) |
|---|---|---|
| 1 | 0.0193 | 0.0358 |
| 2 | 0.0114 | 0.0256 |
| 3 | 0.0083 | 0.0240 |
| 4 | 0.0055 | 0.0126 |

When compared to the measurements in section 1.10.3, the measurements highlighted in red in Table 4 indicate cases in which the maximum fragment size exceeds the available clearance gap between the bearings and pivot ends (illustrated in Figure 12).

Several fragments may also have been co-located and thereby jointly exceeded the size of the separate fragments.

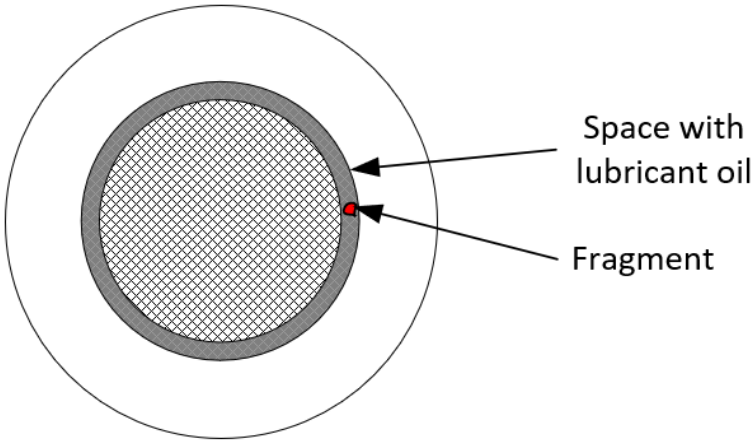


*Figure 12: Sketch of bearing, pivot end, bore and fragment. Sketch: NSIA*

### 1.10.5 INVESTIGATION OF EXTERNAL IMPACTS AT JAR STATION

On 20 January 2022, the NSIA inspected and collected photo documentation of the infrastructure and signal box at Jar station. The signalling system was built in connection with the reconstruction of the Kolsås line and delivered in its entirety by Siemens Mobility in 2011. The local interlocking system is of the Westrace type from Siemens Mobility. The signalling system is computer-based, and interlocking is incorporated in the signalling software. The relays in the system are primarily used to detect track occupation, and the output from the relays indicate to the computers whether or not a track section is occupied. The system is monitored and remotely controlled from T-banen's central traffic management centre.

The NSIA asked Sporveien T-banen to document and log various parameters in the signal box at Jar. The NSIA wanted documentation to be able to consider or exclude possible interference on the relays as a result of recurrent/persistent current, resistance and voltage loads. There were also factors relating to magnetic interference that might be relevant to the examination of the relay itself. Clarification of the sequence of events had depended on this type of logging in a previous investigation[2] relating to Sporveien's signalling system.

After submitting several requests, the NSIA was informed that Sporveien T-banen did not wish to carry out such measurements as they considered that such logging would not contribute to ascertaining the causes of the incident. The results of the fragment examinations were available by this time, which supported the theory that the fault was mechanical. The NSIA may demand that investigations be carried out, but in the present case, it was not considered expedient to initiate any further examination of the signalling system without the cooperation of the infrastructure manager. The safety investigation can therefore not exclude external electromagnetic interference on the relay as no measurements were carried out.

On 13 July 2022, the NSIA received supplementary documentation from Sporveien T-banen relating to electromagnetic compatibility (EMC) of VT1 relays. The document[3] was prepared by DB Engineering & Consulting Gmbh in connection with the commissioning of SL18, a new tram type.

The report states, among other things:

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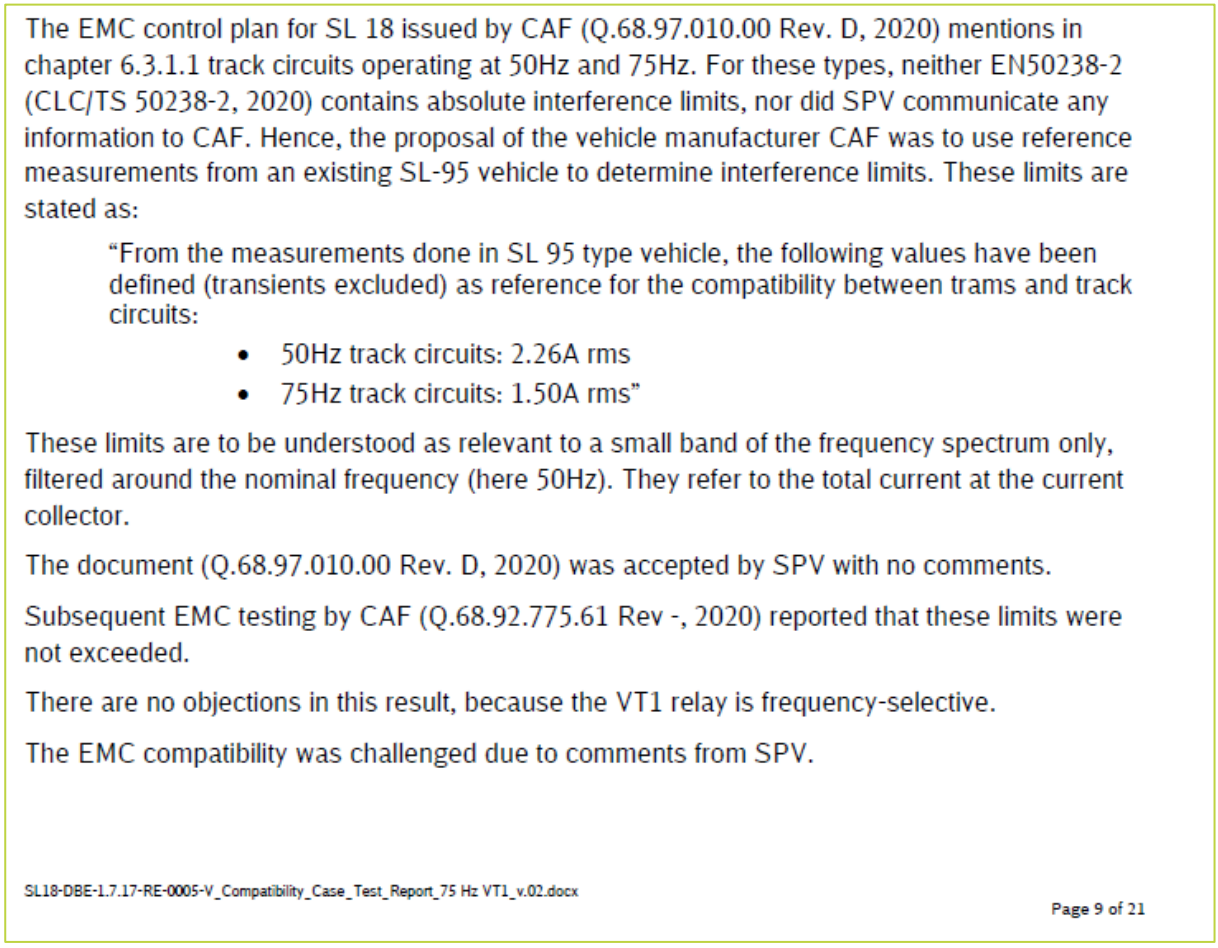
[2] *2021/02 Report on wrong side signal failure at Grønland Metro Station on 2 March 2020.*

[3] *SL 18 Tram Sporveien 3rd Party assessment for Testing & Commissioning Compatibility Oslo infrastructure/ signalling Framework ID: RAM-00645 Framework Title: Technical Advice support Compatibility Case Report TDS – 75 Hz VT1 track relay*

*By their design, two element AC induction track relays are immune to frequencies that differ considerably from the local frequency. They are also phase sensitive.*

Figure 13 contains an extract from the report 'SL 18 Tram Sporveien 3rd Party assessment for Testing & Commissioning Compatibility Oslo infrastructure / signalling Framework'.[3]



The EMC control plan for SL 18 issued by CAF (Q.68.97.010.00 Rev. D, 2020) mentions in chapter 6.3.1.1 track circuits operating at 50Hz and 75Hz. For these types, neither EN50238-2 (CLC/TS 50238-2, 2020) contains absolute interference limits, nor did SPV communicate any information to CAF. Hence, the proposal of the vehicle manufacturer CAF was to use reference measurements from an existing SL-95 vehicle to determine interference limits. These limits are stated as:

> "From the measurements done in SL 95 type vehicle, the following values have been defined (transients excluded) as reference for the compatibility between trams and track circuits:
>
> - 50Hz track circuits: 2.26A rms
> - 75Hz track circuits: 1.50A rms"

These limits are to be understood as relevant to a small band of the frequency spectrum only, filtered around the nominal frequency (here 50Hz). They refer to the total current at the current collector.

The document (Q.68.97.010.00 Rev. D, 2020) was accepted by SPV with no comments.

Subsequent EMC testing by CAF (Q.68.92.775.61 Rev -, 2020) reported that these limits were not exceeded.

There are no objections in this result, because the VT1 relay is frequency-selective.

The EMC compatibility was challenged due to comments from SPV.

SL18-DBE-1.7.17-RE-0005-V_Compatibility_Case_Test_Report_75 Hz VT1_v.02.docx

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*Figure 13: Extract from report on EMC compatibility. Source: Sporveien T-banen AS*

Based on the above-cited report, Sporveien is of the opinion that the possible presence of external frequencies cannot impact this type of relay.

Since the NSIA lacks documentation of any external impacts affecting the signal box at Jar the NSIA has not conducted any further assessments or challenged the reliability of the report on this point.

## 1.11 Laws and regulations

The present investigation has focused on maintenance of components in Sporveien T-banen's signalling system. The operation of metro infrastructure is regulated by the Regulations of 10 December 2014 No 1572 relating to requirements for tramways, underground railways, suburban railways etc. (Requirements Regulations), which lay down minimum requirements for management of operations to maintain or improve safety levels. The regulations also apply to the operation of infrastructure, including signalling systems.

The Act of 3 June 2005 No 34 on Notification, Reporting and Investigation of Railway Accidents and Railway Incidents etc. (Railway Investigation Act) has also been of relevance to conducting the investigation.

## 1.12 Safety management – internal rules and procedures

Sporveien T-banen has a safety management system in place that forms the basis for being authorised by the Norwegian Railway Authority to conduct infrastructure operations, traffic services and traffic management on the metro network. The management system sets out requirements for contractors such as Sporveien and its sub-contractors, in this case Siemens Mobility.

Sporveien T-banen has technical regulations in place that include requirements for track sections.[4]

Requirements for maintenance of train detection systems are set out in a separate document.[5] In addition, there are several specific maintenance instructions that also describe the competence requirements that apply to those who carry out such maintenance.

Requirements for overhauling track relays are described in document K1-T-300-10 version 8.00/02.08.2016:

| ID | S-pkt | Kilde Krav* | Komponent | Beskrivelse av aktivitet | Utført sign | Merknad |
|---|---|---|---|---|---|---|
| 1. | S | | | **Revisjon av sporfeltrelé**<br>- Sporfeltrelé erstattes med et nytt/revidert relé, og leveres til revisjon hos leverandør.<br>- Alle innstikk (kontaktfjærer) må sjekkes etter utskifting av releer. Skiftmelding fylles ut og meldes IFS. Benytt skjema K1-IE-V-1 Melding om bytting/flytting av komponenter og individer | | |

*Figure 14: Requirements for use of suppliers to overhaul track relays. Source: Document K1-T-300-10 version 8.00/02.08.2016*

Figure 14 summarised:

Overhaul of track relay:

- To be replaced with a new relay or a relay overhauled by the supplier, the old relay is to be delivered to the supplier for overhaul.
- All contact pins must be controlled after a relay replacement. Notification of replacement is to be sent in the IFS system.

## 1.13 Incidents of a similar nature

There are few records of incidents relating to faulty VT1 relays. In the course of the investigation, the NSIA has learnt about some individual incidents. These incidents also relate to operators other than Sporveien T-banen:

- In one case, the relay had remained closed as a consequence of extraordinary wear on the vane's stop plate/contact plate and where the relay contacts got stuck / mechanical conditions prevented the vane from returning to the open position (Figure 15). This fault is common knowledge, and is followed up by Sporveien T-banen in periodic inspections described in the standard job procedure 'Standardjobb 20'. The inspection is carried out visually and is easily done by the signal engineer. The fault is known to have occurred in several similar systems and, as far as the NSIA is aware, it is dealt with by infrastructure managers who use this type of relays.

[4] *IE-TB0000-300- AC-0007 Chapter 4 'Togdeteksjon' version 03G/27.09.2011*

[5] *IE-TB0000-300-AC-1013 version 03G/27.09.2011*

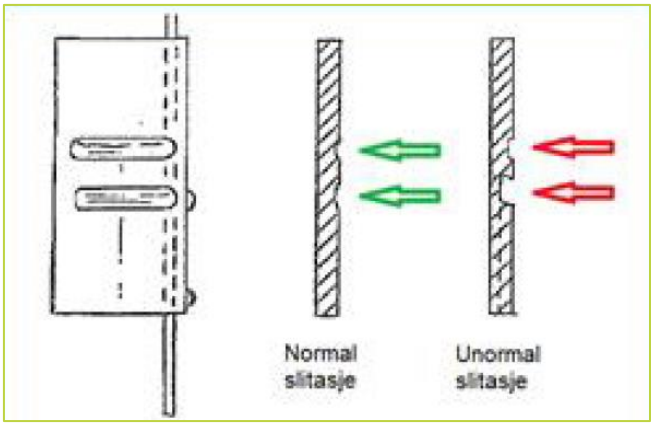


*Figure 15: Description of fault where the VT1 relay's stop plate/contact plate has suffered extraordinary wear. Source: Sporveien T-banen 'Standardjobb 20' version 10.20.*

- In winter 1994, a similar incident to the one at Jar occurred at Majorstuen station, where a train received permission to proceed without restrictions onto an occupied track section. The investigation of the incident showed that the relevant track relay had been subject to major external impact because a snow clearance vehicle had run into the signal box.
- One incident of the relay not closing as intended. Investigations showed that the relay, in connection with handling during storage, had fallen to the ground from a height without this being reported.

# 2. Analysis

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## 2.1 Sequence of events

On 27 November 2021, a situation occurred at Jar station when track circuit 839 failed to present the track section as occupied while there was rolling stock on the track. The metro's traffic controller quickly became aware of the situation and handled it in accordance with applicable procedures. The situation had no consequences in this case, but track detection failure means that the signalling system cannot detect trains, which increases the risk of vehicle collisions.

When troubleshooting the relay, Sporveien T-banen's personnel found that it had not opened as intended. Nor did it open when it was de-energized. The relay did not open until it was physically removed from its base. The relay was reinstalled and functioned in the normal manner. The signal engineer nonetheless considered that the relay should not remain in operation, and the relay was replaced.

Train detection failure is a dangerous condition that can cause collisions between vehicles, sometimes at high speeds. The signalling systems are therefore closely monitored sub-systems followed up through requirements for inspection, maintenance and overhauls.

The relay in question (VT1-6F-4B) is of a recognised type, commonly used by infrastructure managers both in Norway and in other countries. The relay had recently been overhauled by the UK manufacturer and supplier, Siemens Mobility in Chippenham, on 25 May 2021, and had been installed in the system at Jar on 17 June 2021. Faults of the type that occurred at Jar are very infrequent, but they are potentially very dangerous. According to the manufacturer, the relays have an estimated lifetime of 10 years or 1 million movements.

The NSIA has addressed two safety issues in the present investigation as the main potential causes of the condition:

- Could mechanical factors have prevented vane rotation?
- Could external interference have manipulated the relay?

## 2.2 Possible mechanical factors preventing vane rotation

The NSIA examined the relay to determine whether vane rotation could have been prevented by mechanical factors. The examinations were carried out in Norway and at the supplier's premises in the UK. It was not possible to recreate the fault that prevented the relay from opening. Nor were any traces of mechanical damage found on any of the moveable components. All moveable parts operated freely and accurately.

The NSIA found that the lateral vane displacement at the pivot was greater than the limit set for final testing and inspection. Nonetheless, the lateral displacement was not great enough to cause the aluminium plate to come into contact with the coils that drive the relay, and it can therefore not explain why the relay did not open.

Furthermore, metal fragments were found in the lube oil when the pivot ends were wiped clean. The fragments were of a brass alloy, the source of which was neither the pivot ends nor the bearing housing. During normal operation, the relay is not expected to produce shavings or fragments, and the horizontal position of the vane makes it highly unlikely that anything could fall, by force of gravity, into the clearance gap between the bearings and pivot ends. The NSIA therefore considers it probable that the fragments entered the bearings when the relay unit was

opened. The relay is normally enclosed and sealed, and the unit is only open during production and overhauls at the factory.

Siemens Mobility gave the NSIA a demonstration of assembly and testing and inspection of a VT1 relay. The sleeves used as bearings for the pivot ends are stored in a box next to the workshop. The sleeves are supplied ready bored with the correct diameter by a sub-contractor. To prevent any dirt from entering the relay when it is assembled, the sleeves are purged with pressurised air before they are mounted in the relay together with the vane. The premises were clean, and both staff and guests were required to wear coveralls. The NSIA is nonetheless of the opinion that there is room for improving testing/inspection and storage of the sleeves.

The NSIA has thereby been unable to ascertain where the fragments came from, but identified the following possible sources:

- exposure of components to contamination from the surroundings as they are stored locally in an open box;
- production shavings.

The NSIA believes there may have been one or more fragments at the tips of the pivot ends during final testing and inspection of the relay in June 2021, which would have left the vane in the correct lateral position at the time. During the period for which the relay was in operation, the fragments may have moved from the tips of the pivot ends to the bearing surfaces. As shown in Table 4, there are several possible ways in which one or more fragments can fill the space between the bearings and pivot ends, and thus prevent rotation. Several fragments may also have been co-located and jointly have exceeded the size of the individual fragments.

The NSIA believes there may be room for improvement in the process for cleaning components with pressurised air at Siemens Mobility. On the other hand, the great number of relays of this type that are in use internationally, seen in relation to the very low number of failures, indicates that the production process does much to ensure that these relays are safe to use. Also, Siemens shortly after the inspection of the faulty relay, changed their assembly process to mitigate the issue. On this background the NSIA does not propose any safety recommendation following the investigation.

## 2.3 Possible manipulation by external impacts

The relay is driven by two separate electricity sources, both of which must be present for the relay to close. Current is supplied by the track circuit and electricity grid, respectively. Designed as a safety relay, it is opened by the force of gravity when one of the electric supplies fail. When a track circuit is short-circuited by a train axle, the voltage at the relay is removed and the relay is supposed to open. An alternative hypothesis to mechanical impact on the vane is therefore that the relay may have been affected by various forms of electrical interference, in the form of either frequency noise or magnetic noise.

The NSIA asked Sporveien T-banen to measure such factors, as had been done in connection with the investigation into a wrong side signal failure at Grønland station in 2020.[2] This type of technical examination requires work in the signalling system and depends on cooperation with the infrastructure manager. In the course of the investigation, Sporveien T-banen came to the conclusion that such measurements were of no use in the case and did not wish to carry them out. Sporveien is of the opinion that the possible presence of external frequencies cannot interfere with this type of relay. Hence, the NSIA is left with theoretical data only for considering the possibility of such impacts. At the time of the request, the results of other examinations were ready. The

mechanical hypothesis was considered such a likely explanation that the request to carry out measurements in the signalling system was dropped.

In an investigation where the direct and immediate cause of a condition is not obvious, the exclusion of relevant hypotheses is an important method of substantiating the most probable cause. In the present case, the NSIA has not been able to exclude the hypothesis of electrical or magnetic interference, and this may have weakened the quality of the investigation. The purpose of the NSIA's investigation is to understand and explain the incident, and to identify possible safety issues. The aim is to enable appropriate steps to be taken to prevent the recurrence of similar incidents or accidents. A less comprehensive investigation means that latent risks may still exist and resources may have been spent on factors that did not necessarily have the highest priority.

# 3. Conclusion

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## 3.1 Causes and contributory factors

On 27. November 2021, a hazardous situation occurred at Jar station when track circuit 839 failed to present the track section as occupied when metro train no 1316 was on the track. This was caused by a track relay that did not open. The relay had been overhauled by the manufacturer and supplier in May 2021, and it had been in operation in the system for less than six months.

The situation had no consequences in this case, but track detection failure means that the signalling system cannot detect trains, which increases the risk of vehicle collisions.

The NSIA has been unable to finally conclude why the relay did not open when the track circuit was short-circuited by the vehicles, but nonetheless concludes that vane rotation was most probably prevented by small metal fragments found in the bearings of the relay's vane.

It has also not been possible to determine how the metal fragments entered the bearings. The relay is a sealed unit that is only opened at the factory. A possible explanation is the way the bearings were manufactured and stored at the factory, or that they were not properly cleaned when reassembled after being overhauled.

The NSIA does not propose any safety recommendation following the investigation. The NSIA does not issue any safety recommendations following the investigation. Siemens Mobility has shortly after the investigation of the relay changed their method for cleaning the bearings in the assembly process

## 3.2 Implemented and planned measures following the incident

Siemens has informed the NSIA that the process has been refined to eliminate the risk of contamination in the pivot bearings:

- All the bearing screws are treated in ultrasonic cleaning tanks to ensure removal of any remaining cutting oil and any particles contained within it.
- The lubricating oil used during assembly is stored in a closed container and applied using a clean syringe style applicator, this prevents any particles entering lubricating oil prior to or during assembly.

These actions were put in place immediately after the visit by the NSIA and are now standard practice.

## 3.3 Other

The NSIA has not identified other factors with a bearing on safety in connection with this investigation.

# 4. Safety recommendations

# 4. Safety recommendations

The Norwegian Safety Investigation Authority submits no safety recommendations following this investigation.

Norwegian Safety Investigation Authority
Lillestrøm, 15 December 2022