MINISTRY FOR
INNOVATION AND TECHNOLOGY

TRANSPORTATION SAFETY BUREAU

# FINAL REPORT


2020-0789-5
(HU-6321)

**Railway Accident / Fire in Rolling Stock**
Biatorbágy, 14 August 2020

# Basic principles of the technical investigation

The purpose of the technical investigation is to reveal the causes and circumstances of serious railway accidents, railway accidents and railway incidents and initiate the necessary technical measures and propose recommendations in order to prevent similar incidents. The technical examination is not intended to examine and determine fault or liability in any form.

The findings of the investigation are based on an assessment of the evidence available and obtained by TSB in the course of the investigation, taking into account the principles of a fair and impartial procedure. In the Draft Report, the persons involved in the occurrence shall be referred to by the positions and duties they had at the time of the occurrence.

TSB shall retain data having come to their knowledge in the course of the safety investigation and shall not be obliged to make the data – regarding which the owner of the data could have refused its disclosure pursuant to the relevant act – available to other authorities.[1]

The Final Report shall not have binding force and no appeal proceedings may be initiated against it.

This investigation has been carried out by Transportation Safety Bureau pursuant to relevant provisions of

- Act CLXXXIV of 2005 on the safety investigation of aviation, railway and marine accidents and incidents (hereinafter referred to as “Kbvt.”);
- Commission Implementing Regulation (EU) 2020/572 of 24 April 2020 on the reporting structure to be followed for railway accident and incident investigation reports;
- MND Decree 24/2012. (V.8.) on the detailed rules of the technical investigation of serious railway accidents, railway accidents, and railway incidents and on the detailed rules of investigation by the upkeeper, and;
- in the absence of other related regulation of the Kbvt., the Transportation Safety Bureau of Hungary conducts the investigation in accordance with Act CL of 2016 on General Public Administration Procedures.

Kbvt., together with MND Decree 24/2012. (V.8.), is to serve compliance with Directive (EU 2016/798 of the European Parliament and of the Council of 11 May 2016 on railway safety (hereinafter: “Railway Safety Directive”).

The competence of the Transportation Safety Bureau of Hungary is based on Government Regulation № 230/2016 (VII.29.) on the assignment of a transportation safety body and on the dissolution of Transportation Safety Bureau with legal succession.

The technical investigation is independent of other administrative, administrative infringement or criminal proceedings, as well as proceedings initiated by employers in connection with traffic accidents and other traffic incidents.

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[1] Pursuant to Sections 18 (1) and (6) of Act CLXXXIV of 2005 on the safety investigation of aviation, railway and marine accidents and incidents

**Translation**

This document is the translation of the Hungarian version of the Final Report. Although efforts have been made to translate it as accurately as possible, discrepancies may occur. In this case, the Hungarian is the authentic, official version.

# DEFINITIONS AND ABBREVIATIONS

| | |
|---|---|
| 1116 048 | The electric locomotive with reg. № A-ÖBB 91 81 1116 048-0 |
| ERAIL | The accident database of the European Union Agency for Railways |
| GTO | Gate Turn-Off Thyristor |
| IC | Investigating Committee |
| Kbvt. | Act CLXXXIV of 2005 on the safety investigation of aviation, railway and marine accidents and incidents (hereinafter referred to as Kbvt.) |
| MÁV Zrt. | Hungarian State Railways Co. |
| MÁV-Start Zrt. | MÁV-Start Passenger Start Co. |
| ÖBB TS | ÖBB-Technische Services GmbH |
| Reg. № | Registration number of a railway vehicle |
| SR2 | Rectifier unit (Stromrichter); 2 rectifier units are installed on the locomotive; the rectifier unit № 2 is involved in the occurrence |
| TSB | Transportation Safety Bureau (Hungary) |
| VTK | Train Data Form (a document indicating data of train composition) |
| ZVEI | Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (representative federation of the German electrical industry) |

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# 1. SUMMARY

On 14 August 2020, malfunctions appeared in the locomotive (reg. №: 1116 048) freight of the train № 92905 moving from Győr to Ferencváros before Biatorbágy Station, which, however, did not prevent the locomotive from moving the train. After the train passed through the station, there was an explosion in the engine room of the locomotive, which tore off even the roof of the locomotive. Some separated parts fell into the clearance of the neighbouring track, the InterCity train № 910 running there crashed with it, and some wagons in the train were damaged externally.

During the investigation, the IC, in cooperation with the organisation responsible for the maintenance of the locomotive revealed that the explosion had been due to the failure of a capacitor. Research into previous similar events in other countries and the destructive inspection of the capacitor provided an explanation for the exact course of the event.

Due to the construction of the capacitor, overheating generated flammable gases which were released and exploded because of the ignition sources present in the electric locomotive. A manufacturing defect, which has not been described more closely, or some circumstance of operation can be assumed as the cause of the overheating.

It contributed to the occurrence that, ca. 2 minutes before the explosion, the locomotive driver received a fire signal, but he judged it a false alarm (there was no actual fire, indeed), and he did not take the expected measures, although it could not be ruled out that, at that time, the explosion was not preventable anymore.

Following the incident, the organisation entrusted with the maintenance of the locomotive has converted to the use of capacitors with different structures and more frequent inspections of the capacitors, and measures have been taken to ensure more rigorous treatment of fire signals.

# 2. THE PROCESS AND CONTEXT OF THE INVESTIGATION

## 2.1 Initiation of the investigation

The occurrence was reported to the duty service of TSB by the Emergency Manager of MÁV Zrt. on 14 August 2020, at 06:48 (12 minutes after the occurrence).

The manager on duty of TSB ordered an immediate inspection of the scene. On the basis of the experience of the inspection, the Head of TSB decided to initiate a technical investigation.

## 2.2 Reason for initiation of the investigation

Pursuant to Section 7 (1) of Kbvt., TSB shall

*1st investigate serious railway accidents;*
*2nd may investigate other transport occurrences, if – in the judgement of the transport safety body – they could have resulted in transport accident in slightly different circumstances, assessing*
- *a) the severity of the accident or railway incident,*
- *b) whether it constitutes a part of a series of events of importance to the whole of the system,*
- *c) the impact of the accident or railway incident on railway safety,*
- *d) any requests from infrastructure managers, railway undertakings, national safety authority branches or Member States;*
- *e) whether it can provide lessons to learn about safety.*

This investigation was initiated on the basis of point 2 (c) above (in line with Article 20 (2) (c) of the Railway Safety Directive), because:

- the locomotive was also seriously damaged in the occurrence, and the consequences of the occurrence posed considerable risk on another train; and
- this type of locomotive is in use in large numbers in several European countries as well, and it is therefore possible to mitigate the risk of similar accidents at international level by exploring the causes and deducing lessons to learn.

## 2.3 Scope and limits of the investigation

The purpose of the investigation was to identify the course of events, to identify the affected people's activities, to identify the human, organisational and technical factors influencing the operation of the technical equipment, to identify direct and indirect causes, to present lessons learnt, and finally, to present any preventive actions taken, and, if necessary, to formulate security recommendations.

This investigation covered the locomotive driver's actions, the operation of the defective component, and its specific failure.

## 2.4 The Investigating Committee

The Head of the TSB assigned the following Investigating Committee for the investigation into the railway incident:

| | | |
|---|---|---|
| Investigator-in charge | Gábor Chikán | Investigator |
| Member | József Kapocsi | Investigator |
| Member | István Mokri | Investigator |

The IC assigned by the Head of TSB had the necessary proficiency and competence to carry out the investigation, but the detailed examination of the failed capacitor necessitated the invitation of an expert. This task was carried out by Vishay Intertechnology in Landshut (Germany) upon order from ÖBB TS co-operating in the investigation.

## 2.5 Communication and consultation processes

The IC interviewed the locomotive drivers (taking audio records of the interviews) at the scene of the occurrence and, in the case of the freight train crew, the IC obtained the minutes of the interview carried out by the railway undertaking.

In the course of the investigation, the IC was keeping in touch with the technical staff of ÖBB TS, the operating undertaking, at the Linz site, and certain steps of the investigation were performed at their premises, and/or in a joint effort.

TSB sent the Draft Report to

- Railway Authority Division, Ministry for Innovation and Technology
- the national investigation body of Austria (BmVIT Sicherheitsuntersuchungsstelle des Bundes)
- MÁV Zrt.
- MÁV-Start Zrt.
- Rail Cargo Hungaria Zrt.
- ÖBB TS

TSB received a written response or comment, addition or proposal from

- Railway Authority Division, Ministry for Innovation and Technology
- the national investigation body of Austria (BmVIT Sicherheitsuntersuchungsstelle des Bundes)
- MÁV Zrt.
- ÖBB TS

The comments did not affect the analyses or conclusions in the Draft Report and agreed with the safety recommendation.

TSB held a closing meeting on 1 June 2021 in order to discuss the the comments received, with the participation of representatives from

- Railway Authority Division, Ministry for Innovation and Technology
- MÁV Zrt.
- MÁV-Start Zrt.

## 2.6 Cooperation

During the investigation, the locomotive was disassembled at the Linz repair shop of ÖBB TS, in the presence of the IC, representatives from the operating entity and from the Austrian accident investigating body.

Upon request of the IC, the manufacturer of the malfunctioned capacitor also provided useful data on its structure, the material used in it, the options of failure and possible gas formation.

## 2.7 Test methods

For the purpose of the investigation, the IC used:

- the findings of the investigation of the scene on 14 August 2020 and of the survey of the locomotive at the Linz site on 25 August;

- recorded data of the substation of the overhead contact line;
- various data recorders of the locomotive;
- the inspected and recorded damages in the engine room of the locomotive;
- the interviews referred to in Chapter 2.5;
- experiences from earlier similar occurrences (4.5).

With the consent of the IC, ÖBB TS assigned Vishay Intertechnology's premises in Germany to examine the locomotive as well as three more capacitors of it (Annex 1.Annex 3).

## 2.8 Difficulties of the investigation

Due to damage to the locomotive, the technical data recorded in the malfunctioned rectifier – which data could have greatly facilitated the exact delimitation of the fault that had led to the explosion – were destroyed.

For the sake of more precise delimitation of the malfunction of the locomotive, such as search for potential transients, the IC attempted to determine the current consumption of the locomotive, but available data did not make it possible to create a sufficiently clear picture (4.2.3).

Preliminary assessment of the soot sample taken in the vicinity of the damaged capacitor did not reveal any substance which would have helped the investigation, and no new information was expected from more detailed and more costly material testing either. In the meantime, an internal analysis of the damaged capacitor confirmed the probable cause of the event, which made the chemical analysis of the combustion product unnecessary.

## 2.9 Liaising with law enforcement and judicial authorities

The Police Bomb Disposal Unit assisted the investigation, and the Disaster Management Service requested and received information from TSB.

No other liaising was necessary with law enforcement or judicial authorities.

# 3. THE OCCURRENCE

## 3.1 Description of the occurrence

Due to earlier malfunctioning, only 3 of the 4 traction motors were serviceable on the locomotive with reg. № 1116 048 of the freight train (№ 92905) moving from Győr to Ferencváros on 14 August 2020.

From 6:34 am, before the Biatorbágy station, the locomotive began to show the signs of various malfunctions, including a fire signal, which, however, did not make the traction of the train impossible, but soon after – following automatic disconnection – only two traction motors were working already. At 6:36 am, after the train had run through the station, there was an explosion in the engine room of the locomotive that tore the top of the locomotive off.

The torn pieces got into the gauge of the other track, and one of them was hit by the InterCity train № 910 which was moving in the opposite direction; its rolling stock suffered external damages.

### 3.1.1 Type of the occurrence

| | |
|---|---|
| Type of occurrence: | R**ailway accident** |
| Nature of occurrence: | **Fire in rolling stock** |
| Other information: | The term “fire in rolling stock” also includes cases of explosion, even without a fire. |

As a consequence of the event, the train on the other track had a “collision with an object” accident. However, the purpose of the test was to identify the causes of the explosion, and the impact was assessed by the IC as a consequence of the explosion.

### 3.1.2 Date and location of the occurrence

| | |
|---|---|
| Date of the occurrence: | 14 August **2020, 06:36 o’clock** |
| Location: | **The national railway network,**<br>**Railway Line № 1 Budapest – Hegyeshalom,**<br>**Biatorbágy Station** |

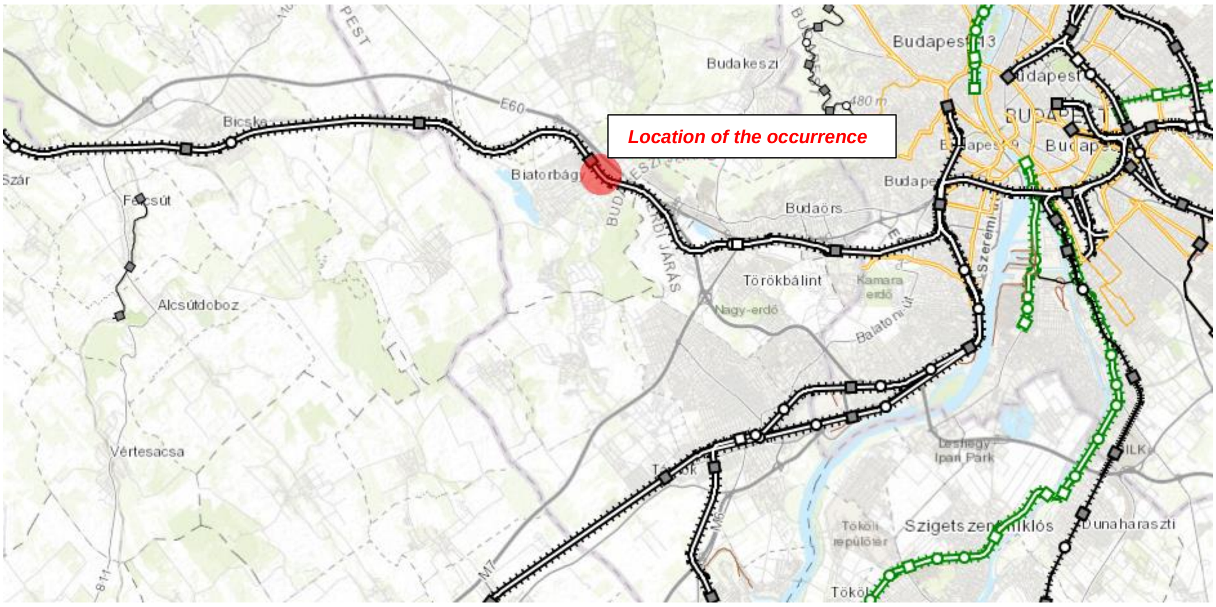


**Figure 1: Location of the occurrence (Map: ArcGIS WorldTopoMap)**

### 3.1.3 Location of the occurrence

Biatorbágy station is in the middle of the inland section of the Budapest - Hegyeshalom dual-track railway line electrified with a 25 kV, 50 Hz system; the occurrence took place between the switching zone and the entry signal at the upside end of the station. The railway track is sunk there, the speed limit on the track is 140 km/h.

### 3.1.4 Consequences

**Injuries to people**

| Injury | Personnel | Passenger | Level crossing user | Trespasser | Other |
|---|---|---|---|---|---|
| **Fatal** | - | - | - | - | - |
| **Serious** | - | - | - | - | - |
| **Light** | - | - | - | - | - |
| **Uninjured** | 1+2 | 0+42 | - | - | - |

The affected personnel included the locomotive driver of the freight train № 92905, and two of the crew of the train № 910: the locomotive driver and the chief ticket inspector of the train № 910.

**Damage to property**

The amount of damage to the train has not been provided by the railway undertaking until completion of this Draft Report, but the IC has estimated that the damage could be a couple of hundred million HUF.

There was no damage to the railway track. In the overhead contact line, a stitch wire broke and two steady arms got damaged, the restoration cost of which was HUF 111,913 in total.

The damage to the passenger train amounted to HUF 3.5 million, plus the railway undertaking suffered additional damage including the cost of HUF 350,000 of the elimination of the consequences of the accident, which gives the total amount of HUF 3.85 million.

**Environmental damage**

There was no environmental damage.

### 3.1.5 Other consequences

Both tracks were closed for traffic between Budaörs and Biatorbágy stations from the time of the occurrence (6:36 am) to 9:51 am, and then the right hand side traffic was released for traffic, but the use of the track from Railway Section 291 to Railway Section 294 was subject to speed limits: 20 km/h initially, and 40 km/h from 10:10 am; the speed limit was lifted at 10:50 am.

After the release of the left track, the recovery of the overhead contact line lasted till 11:38 am, and then the track was released for traffic at 11:41 am.

Because of the restrictions:

- 5 passenger trains were cancelled all along the line;
- 1 passenger train had to take a detour;
- 27 passenger trains were partly cancelled;
- 36 passenger trains had a combined total delay of 704 minutes;
- 2 freight trains had a combined total delay of 561 minutes.

Nine replacement buses were provided for the transport of passengers because of the cancelled trains.

### 3.1.6 Entities and people concerned

The railway track is operated by MÁV Zrt.

The train № 92905 was managed by Rail Cargo Hungaria Zrt. (hereinafter: „RCH Zrt."), and the train 910 was managed by MÁV-Start Zrt.

The operator of the locomotive with reg. № 1116 048 P in Hungary is RCH Zrt., and the organisation responsible for tis maintenance is ÖBB TS Ltd..

### 3.1.7 Trains

The freight train № 92905, transmitted from Győr to Ferenc Győri by the locomotive with reg. № 1116 048, was involved in the event:

| | |
|---|---|
| Number of wagons: | 21 pcs. |
| Length: | 308 m |
| Mixed weight: | 874 t |

as well as the long-distance passenger train (Intercity) № 910, transmitted from Budapest to Szombathely, by the locomotive with reg. № 0470 008 (Intercity):

| | |
|---|---|
| Number of wagons: | 3 pcs. |
| Length: | 100 m |
| Mixed weight: | 240 t |

### 3.1.8 Infrastructure

Description of the railway infrastructure in more details than the characteristics described in Chapter 3.1.3 above is irrelevant to the occurrence.

## 3.2 Course of events

On the basis of the evidence obtained, the actual course of the events could be summarised as follows:

### 3.2.1 Events before the occurrence

The capacitors in the high-voltage traction current of the locomotive were continuously losing their capacity during operation.

2016 to 2020: The capacity loss became faster.

**As of 17/07/2020** The locomotive was operated with three traction motors due to a malfunctioned GTO unit.

### 3.2.2 Course of events

| | ***92905 freight train (on LH track, towards upside end)*** | ***910 passenger train (on RH track, towards downside end)*** |
|---|---|---|
| | The capacitor C2 in the rectifier cabinet SR2 got overheated, which made its polypropylene component degrade to combustible gases, while its inner structure charred. | |
| **6:34:27** | Smoke and combustible gas flowed out of the capacitor, which resulted in a fire signal at the driver's position.<br>The operating principle of the fire alarm in the current cabinet is optical, therefore smoke or soot in the atmosphere triggers its signal. Since there was a considerable spot of soot in the current cabinet near the capacitor, the IC supposes that, at that time, there was at least smoke leakage from the malfunctioned capacitor. | |
| | The driver looked into the engine room, but he saw neither fire nor smoke, so he continued his way despite the active fire alarm.<br>Since the smoke was leaking in a locked cabinet within the engine room of the locomotive (where the locomotive driver had looked around), it could not get out. | |
| | The rectifier has internal air circulation which thus was able to disperse the combustible gas in the available space. | |
| **6:34:59** | Because of the short in the rectifier, | |

| | ***92905 freight train*** ***(on LH track, towards upside end)*** | ***910 passenger train*** ***(on RH track, towards downside end)*** |
|---|---|---|
| | which was almost certainly originating the capacitor already, the main circuit breaker switched off temporarily, and the rectifier SR2 did no longer turn on again.<br><br>The locomotive gave a short-to-ground signal, which is confirmed by the contents of the technical data recorder. Based on the nature of the failure and the fact that the SR2 no longer worked, it can be concluded that the defect was generated inside it, and was caused by the capacitor (the malfunctioned component found), The SR2 rectifier was disabled automatically by the control unit of the locomotive. | |
| **6:35:26** | After the pre-charge/discharge protection problem following the driver's first attempt to reconnect, the main circuit breaker switched off again, but 5 seconds later, it was able to the power the locomotive up again – now without the rectifier SR2 and the two traction motors linked to it. | |
| **6:36:40** | | The train on the other track was passing through the phase separation section.<br><br>Then the locomotive driver turned the main circuit breaker back on. |
| **6:36:44** | The combustible gas leaked out of the capacitor had mixed with air in the meantime, and was inflamed.<br><br>The IC identified no specific ignition source, but there are a number of components in the electric locomotive in which sparks may occur during normal operation.<br><br>An explosion (very fast combustion) took place in the rectifier cabinet, which seriously damaged the engine room and the body of the locomotive, and consequently, two roof elements got separated from the locomotive. | |
| **6:36:54** | | The locomotive driver of the train perceived the parts fallen from the freight train, and applied emergency |

| | 92905 freight train (on LH track, towards upside end) | 910 passenger train (on RH track, towards downside end) |
|---|---|---|
| | | braking. |
| **6:36:59** | The train № 910 hit one of the fallen roof elements. Of the two roof elements, a corner of the item fallen sooner was at the same height as the spot of damage to the passenger train. | |
| **6:37:07** | The freight train stopped. Due to damage to it, the data recorder did not record the stop of the rolling stock already. The time of stopping is therefore the value estimated on the basis of the distance between the location of the explosion and the location of stopping and the speed at the time of the explosion. | |
| **6:37:22** | | The passenger train stopped in the switching zone of the station. |

### 3.2.3 Events following the accident

The locomotive driver of the passenger train № 910 hurried to the freight train and found that its locomotive driver had not been injured in the accident.

The locomotive driver of the freight train was not able to leave the driver's position through the normal route because of the wrecks in the engine room therefore he left through the emergency exit door of the driver's position.

**09:38** The fallen wreckage was removed from the track clearance.

**09:51** Transport was launched at 20 km/h speed on the right hand side track.

**10:04** A fire inspector of the Disaster Management Service arrived at the scene, but he reviewed the locomotive with reg. № 1116 048 only subsequently, at the mechanics facility at the Ferencváros site.

**10:10** The speed limit was increased to 40 km/h on the right hand side track.

**10:38 - 11:06** The damaged freight train was towed to Budaörs station by a booster locomotive.

**10:50** The speed limit on the right hand side track was lifted.

**11:41** The traffic was restarted on both tracks on completion of repair of the overhead contact line (11:38).

# 4. ANALYSIS OF THE OCCURRENCE

## 4.1 Tasks of people and entities

### 4.1.1 Maintenance

The maintenance organisation of the locomotive is ÖBB TS; actual repair interventions were carried out by several workshops.

It was recognized during a maintenance period in 2017 already that the reduction in the capacity of the capacitors used in the locomotive type involved in the accident had become more frequent before the end of their lifetime, and therefore the frequency of capacity measurement was reduced from 2 million km to 400 000 km.

Measurement in the locomotive affected by the occurrence took place in June 2016 and August 2019, with satisfactory results in both cases for the capacitor concerned, but the values impaired approximately 5% between the two measurements. (The capacity of a capacitor in the circuit not involved in this case decreased to about half; the defect was eliminated by replacing the part.) The locomotive ran 201,313 km between the measurements carried out in 2019 and the date of the occurrence.

The detailed examination of the malfunctioned capacitor that had caused the accident (Annex 1.Annex 3) confirmed that its failure also entailed a prior reduction in capacity therefore the monitoring of capacity would also bring about a reduction of this safety risk, in addition to avoiding unserviceability. The examination of the capacitor did not reveal the speed of the process of impairment for the capacitor which started to malfunction, but it may be stated for sure that more frequent checks would be more likely to identify critical capacitors.

In this context, the following actions have been taken in the area of maintenance:

- out-of-line checks on all locomotives,
- from now on, periodic measurements will be performed after every 100 000 km,
- in the case of a failure, the capacitors will now be replaced in pairs (since the required capacitor capacity in the locomotive is achieved by parallel connection of two capacitors),
- Capacitors of a different design will now be installed in the case of replacement.

## 4.2 Rolling stock and technical equipment

### 4.2.1 Capacitors of the rectifier

#### 4.2.1.1 Malfunction of the capacitor

The occurrence can be traced back to the capacitor type Epcos B25650D2208A064 of the so-called intermediate circuit capacitor (marked C2) in the SR2 rectifier.

The construction of these capacitors is such that if – due to the deterioration of the dielectric strength – a minor puncture occurs between its armatures, the capacitor will be capable of self-healing, which maintains serviceability of the capacitor despite the defect, but its capacity will decrease. However, if such self-healing process takes place too often, it will leads to harmful overheating.

The capacitor test showed a lot of traces of this self-healing process (Annex 1.Annex 3), which, according to the person who tested it, but in a much higher number than normal in a capacitor of this type.

The dielectric of the capacitor is a polypropylene film that decomposes into combustible gases in the case of overheating (Annex 1). After the capacitor was opened it was clearly visible that overheating had occurred, i.e. combustible gases had also been present.

**Figure 2: The inside of the capacitor**

This design and the material used carry the risk of explosion, as shown by similar earlier events in the world (4.5).

Capacitors of this type do not offer a solution to:

- detect overheating,
- detect the accumulation of gases increasing internal pressure and/or
- ventilate the released gases in order not to reach the amount required for the explosion.

According to the capacitor manufacturer's information:

- at the time of the production of that capacitor, the technology used represented the state of the art, but there is already a technology that significantly reduces the risk of this type of malfunction. Experience has shown that when the new technology is used, gases are much less likely to occur during overheating/melting. The customers interested in railway traction already purchase the new type.

– When power capacitors are used, the ZVEI association and the manufacturer[2] also recommend the installation of protective equipment such as an overpressure relay.

During the occurrence, the SR2 power rectifier cabinet was shut down by the locomotive's automatic system 105 seconds before the explosion. Even though the harmful processes in the capacitor no longer received external power supply, the capacitor, being an energy store itself, still had the sufficient energy to sustain the process. Its manufacturer also said, "on the basis of information available to us, we can say that once the condenser is separated or the inverter is stopped, the melting process will slow down and stop."

The slowing process, however, still produces more gas and, because of the dispersal of the gas generated earlier, it was also confirmed that the explosion had occurred only after the disconnection.

#### 4.2.1.2 Lifetime

According to its data sheet, the expected lifetime of the capacitor is 180 thousand hours (approx. 20 years). The capacitor concerned was produced in 2003 and was installed in the locomotive that year, according to information from ÖBB TS. The 17 years past are close to the life span, but experience has shown that actual life expectancy is shorter (4.1.1).

The known capacity values for the undamaged capacitor pair show the following changes:

| | |
|---|---|
| 2003 | 4140 µF [3] |
| 21/06/2016 | 4020 µF |
| 27/08/2019 | 3700 µF |
| 13/10/2020 | 2501 µF |

It is evident that the substantial decrease in capacity started between 2016 and 2019 and then it accelerated sharply.

The experts who inspected the capacitor found that there was a disproportionately high number of traces of self-healing in the capacitors compared to the duration of their use, which was most probably due to a manufacturing defect or the circumstances of operation (e.g. overvoltage) (Annex 1.Annex 3).

The operator also noted that capacity reduction of this capacitor type had been a frequently occurring problem (4.1.1), so they began to substitute such capacitors in the locomotives of the company. However, the results did not reflect the relation between capacitor failure and the characteristic mode of use of the locomotive (whether used in passenger or freight trains).

### 4.2.2 Fire alarm

The first sign of the occurrence was a fire alarm, 137 seconds before the explosion. As a result, the locomotive driver had a look inside the engine space, but, as he saw no fire or smoke, he did not consider it an emergency.

According to information provided by the railway undertaking, activation of the fire alarm

[2] https://www.tdk-electronics.tdk.com/download/530870/f013854d18c20c0542b7ba8947154721/pdf-zvei-general-safety-power-capacitors.pdf
[3] The nominal value, due to lack of data measured during assembly

- occurs occasionally due to the characteristics of the air compressor (notifications are received on several occasions per year, usually by telephone); and
- occurs less frequently in the rectifier cabinet, due to sensor error.

When in warmed-up state, the oil level in the air compressor should be between the min. and max. values. So, with a cold air compressor, the oil level may fall below the min. value, and inexperienced personnel may initiate refill. On the other hand, the compressor removes excess oil from itself, and sooner or later the oil separator will also be saturated, and oil will get into the air system. The valves of the alertness equipment and warning train control system are installed in the vicinity of the compressor, and those valves release the pressure of the main line through a large cross-section when the equipment is triggered. During that, the oil in the system will also be vaporized into that space, and the oil mist may trigger the optical beam smoke detector in the engine room.

Due to false fire alarms, the train crews may not consider the fire alarm to be a serious, dangerous condition, in particular when no smoke or flame is detected by visual inspection of the engine room. But, because the engine room contains closed cabinets, it is possible, as in this case, that the fire or smoke does not escape into a space which is controlled visually the driver.

See also Chapter 4.3.1.

### 4.2.3 Current collection of the locomotive

For the sake of a more precise delimitation of the locomotive's fault and searching for potential transients, the IC attempted to determine the current collection of the locomotive. Since the locomotive does not have a specific data recorder (only one-minute averages), the test is based on the power data of the overhead contact line.

However, only one of the three known other trains running within the same supply section was able to provide a reliable picture of the current collection, so the investigation in this direction did not bring sufficiently accurate results.

## 4.3 Human factors

### 4.3.1 Fire alarm management

The locomotive driver did not consider the fire alarm indicating the start of the process as an emergency. Such behaviour may occur if

a) false alarms occur occasionally, so, in the absence of visible signs, one supposes that it is just another false alarm (taking an error as normal);
b) one is not aware that, due to the closed cabinet design, a fire burning inside a cabinet may not necessarily be visible in the space controlled visually by him/her (lack of theoretical knowledge and/or practical experience);
c) there is a strong external or internal motivation to move the train, which one would not wish to hinder due to an extraordinary stop that may prove to be unnecessary subsequently (conflicting objectives).

An earlier similar occurrence in Australia (4.5.2) was also preceded by multiple resets of the protective measures, i.e. failure to take potential risks into account.

Counter-measures to prevent it:

- adequate education, in particular by raising awareness of point b);
- develop a work culture in which the locomotive driver does not feel (is not made to feel) uncomfortable if the train is delayed in the event of a fire alarm (and other protection measures) which proves to be false subsequently.

### 4.3.2 Other

The course of events shows that the explosion occurred almost two minutes after the faulty circuit had been shut down, but it is almost certain that the combustible gas was already present at the time of the switch-off; so there was a direct danger of explosion at that time.

Therefore, it cannot be stated that, if the train locomotive driver had stopped the train upon the fire alarm or short circuit signal, the explosion would have been avoided for sure, although its probability would certainly have been lower.

On the other hand, entering the engine room of the locomotive (whether with the purpose of leaving the locomotive or troubleshooting) would have been life-threatening for the locomotive driver. (Due to the design of the locomotive, the locomotive driver can leave the driver's position through the engine room).

## 4.4 Safety procedures

According to the manufacturer of the capacitor, “there is no sure way to predict the overheating/melting failure. A potential indicator (but only with a certain level of probability) may be the increase in creep current, and not the loss of capacity. However, this increase represents an increase of 10 milliamperes, which, in our view, makes it extremely difficult or even impossible to detect such an increase out in the field, given that the ampere values during normal operation are in the order of hundreds”.

The examination of the malfunctioned capacitors, on the other hand, supports the fact that the decrease in capacity is linked to the self-healing processes that took place, and that is linked to a risk of overheating and gas formation.

Monitoring the capacity of capacitors therefore reduces the risk of such failure, especially when done more frequently. Accordingly, the frequency of measurements has been increased further in the maintenance system after the occurrence. (4.1.1)

## 4.5 Comparison to previous occurrences

The IC has also collected and reviewed the reports of several similar incidents which had occurred in the UK and Australia.

### 4.5.1 7 July 2017, Guildford (UK)

An earlier DC motor train set was upgraded with a three-phase propulsion, using 11 mF[4] capacitors.

On the day of the incident, an explosion occurred in a motor train set of this type, with no personal injury, but smaller pieces of debris caused damage even 70 meters away from the rolling stock.

The British accident investigation body (RAIB) concluded that, due to the capacitor's manufacturing defect, an internal fault and overheating developed, resulting in the formation of combustible gas from the materials of the capacitor. The pressure of the gas ruptured the capacitor's house and the released gas caught fire.

In the light of the investigation, the manufacturer of the capacitor (not the same as in this case) modified the production technology and introduced a protective measure (pressure switches) against the accumulation of gases in the capacitor housing.

[4] 11 000 µF

### 4.5.2 20 March 2017, Burwood (Australia)

In one of the suburban railway lines of Sydney, there was an explosion in the third car of an electric motor train set with three-phase propulsion powered by an overhead contact line of 1500 V DC.

As a result of the explosion, a handhold in the passenger compartment was deformed, causing a light injury to a passenger, and pieces of wreckage separated from the motor train set (4 pieces of the roof) and fell on the platform.

The Australian Office of Transport safety Investigations (OTSI) found that the traction inverter had originally been designed to be installed on the bottom of the wagons, but this was not possible because of the double-deck design of the train, so such components were installed on the roof, but the insulation class was not changed, so the rainwater got into the unit.

In addition, due to manufacturing failures of the capacitors, an internal short circuit and overheating developed.

The presence of both malfunctions caused the formation of acids and combustible gases, (synthesis gas). The accumulated gases got from the capacitors into the open space, where they were ignited by electric arc.

On the day before the event, the motor train set involved in the accident had the capacitor overvoltage problem several times during the working hours of two drivers. Consequently, the traction inverter module was switched off by the protective function, but later on it switched back on automatically. As wheel adhesion problems are relatively common with the motor train set, the switch off and switch back on of the traction inverter module were treated by the drivers as normal state.

In relation to the event, the operating company has had all filter capacitors of this type of electric motor train sets replaced. The software of the traction inverter module has been updated and now it includes a locking function to prevent the resetting of the protection and also includes the overvoltage protection of the filter capacitors.

# 5. CONCLUSIONS

## 5.1 Summary

### 5.1.1 Causes and effects

Acts, errors, events or conditions, or combinations thereof, which, in the event of repair, elimination or avoidance, could have prevented the occurrence of the accident or incident in all likelihood:

a) one capacitor of the locomotive was overheated, and produced a combustible gas which inflamed (4.2.1), because
   - the materials of the capacitor decompose as a result of heat (4.2.1); and
   - the detection and venting of such gases is not ensured (4.2.1);

b) the failure can be traced back to the capacitor's manufacturing defect, or possible overvoltage (4.2.1).

### 5.1.2 Contributing factors

Acts, errors, events or conditions that influenced the event by increasing the risk of occurrence, accelerated the effects or increased the severity of the consequences, but the elimination of which would not have prevented the occurrence of the event:

a) The locomotive driver did not respond adequately to the fire alarm that had appeared (4.3), false fire alarms do occur (4.2.2).

### 5.1.3 Systemic factors

Causal or contributing factors, such as of organisational, managerial, social or regulatory nature, likely to have an impact in the future on similar and connected events, including in particular the regulatory framework conditions, the design and application of the safety management system, personnel skills, procedures and maintenance:

a) the failure of the capacitors had been a known phenomenon, but its safety risks were underestimated (4.1.1).

## 5.2 Actions taken

ÖBB took the following measures during the investigation:

- locomotive drivers were ordered to manage the error signals strictly (Annex 1.Annex 2);
- an immediate capacity measurement was ordered for all (332 pcs.) locomotives;
- the rules of periodic monitoring of capacitors has been revised, with more frequent measurements and a more rigorous approach to errors (4.1.1);
- similar capacitors of locomotives are switched to the oil-filled products of another manufacturer.

## 5.3 Other comments

The IC identified no such factors which are not linked to the occurrence but increase risk.

## 5.4 Useful or effective investigation methods

The IC identified no such circumstance or action which would have served the mitigation of the consequences of the occurrence or the avoiding of more serious consequences.

## 5.5 Lessons learnt

In the occurrence concerned, the failure of a component (a capacitor produced in large series) which had worked well for almost 20 years caused an accident involving substantial damage and the potential of an even worse outcome. The capacitor exhibited phenomena hinting at the end of its lifetime well before the service life specified by the manufacturer (4.2.1.2). In the case of such experience contrary to specification data, the operating company may also take preventive actions.

Such series of malfunctions identified a few years before the occurrence concerned entailed a safety risk as well, due to the capacitor's design (formation of combustible gases).

Similar occurrences can be prevented by using a capacitor with a different structure, by more active monitoring of the state of the capacitors, and by recognising the significance of their defects from the aspect of safety.

In addition, the risk may be reduced by the locomotive driver by taking the necessary measures in the event of a signal from a protective function (fire alarm in the case concerned) (4.3.2).

# 6. SAFETY RECOMMENDATION

The probability of similar cases has decreased significantly owing to the measures taken and therefore the IC does not consider it appropriate to issue a safety recommendation.

# 7. DIVERGENT OPINIONS

None of the IC members expressed any dissenting opinion. No divergent opinion was received.

Budapest, 1 June 2021

Gábor Chikán
Investigator-in-charge

József Kapocsi
IC Member

István Mokri
IC Member

# ANNEXES

Facts which have had significant influence on the occurrence and/or its investigation, and have not been presented in other form in the Draft/Final Report.

## Annex 1. Materials used in the capacitor, and their degradation products

The translation by the IC of the information sheet (with its format retained) provided by the manufacturer of the capacitor is as follows:

MKK-DC capacitor
B25650-D2208-K064

The capacitor contains the following substances:

Metals:
- stainless steel for the housing
- copper for the connections
- lead-tin alloy (tin content: 40%) for soldering electrical connections
- tin for metallisation of the film and electrical connection of the film

Plastics,
- Polypropylene for the film, internal insulators and fillers.
- Epoxy for the connections (outer parts), plates and springs.
- Polyester for the connections (inner part)

In the event of a failure of the capacitor, combustible gases and other substances may be generated. The following gases have been identified.

| **Gas** | **Content (%)** |
|---|---|
| Nitrogen | 51.84% |
| Methane | 9.86% |
| Ethane | 5.04% |
| $CO_2$ | 1.17% |
| Propane | 8.71% |
| Propylene | 19.32% |
| I-Butane | 0.27% |
| N-Butane | 0.33% |
| I-Butene | 2.76% |
| C-2 Butene | 0.70% |
| T-2 Butene | |
| I-Pentane | |

Further unspecified amounts of hydrogen and acetylene are also possible.

# Annex 2. Directive issued during the investigation

The railway undertaking issued the following directive and similar directives were issued also by other companies of the group.

File number: 2020-92-A

**Instructions for the work to do on ES64U2 locomotives if certain error messages appear on the display.**

**Start of effect: Date of issue**

Type ES64U2 locomotives shall be treated subject to the instructions given in this Directive, or otherwise the locomotive may suffer a very serious damage.

**1. Fire or smoke signal on the display**

Example:

| |
|---|
| Error signal № 0371: Fire in rectifier (“Brandalarm Stromrichter”) |

**The main circuit breaker shall be switched off immediately and the pantograph lowered. The train shall be** moved on using its momentum (if necessary, for example, in a tunnel) and then **stopped at the nearest suitable location**. The instructions appearing on the display shall be followed.

**The main circuit breaker shall under no circumstances be switched back on even** if there is no fire or smoke in the engine room or if the fire signal disappears from the display. Exception to this is the case where the train stops in a tunnel. In such a case, in order to speed up the train, the pantograph shall be raised and the main circuit switched back on in order to accelerate the train to the adequate speed. When the required speed is reached, the main circuit breaker shall be disconnected and the pantograph lowered. The train must be stopped after leaving the tunnel.

**2. Error signals referring to rectifier error („gestörte Stromrichter“):**

Examples:

| |
|---|
| Error signal № 0026: 100 Hz surveillance (“100Hz Überwachung”) |

| |
|---|
| Error signal № 0465: 1. rectifier pre-charge and discharge surveillance („Vorlade-/Entladeüberwachung SR1”) |

| |
|---|
| Error signal № 0466: 2. rectifier pre-charge and discharge surveillance („Vorlade-/Entladeüberwachung SR1”) |

**The train may be moved to its terminal station,** and then the locomotive shall be taken to the repair yard for inspection of the rectifier.

The driver shall refer the locomotive to the nearest repair yard even if the displayed shows the “Proceed” (“Weiterfahrt”) message.

Relying on the above procedure, we intend to prevent accidents similar to that of the locomotive with reg. mark 1116.048 in Hungary.

# Annex 3. Destruction testing of capacitors

ÖBB TS, in agreement with the IC, assigned Vishay Intertechnology's site in Germany to examine the damaged capacitor as well as three more capacitors removed from the damaged locomotive. Major findings of the test report as extracted by the IC (relying on the translation provided by the operating company):

The capacity of the undamaged capacitors of the four intermediate circuit capacitors delivered was also below the nominal value (2070 µF):

- C1 455.68 µF
- C2 damaged
- C3 924.84 µF
- C4 1576.35 µF

**Layout of the capacitor**

The capacitors are made up of 32 metal-coated flat windings arranged in two columns of 16 windings side by side. The metal-coated surfaces of each winding are connected by a single-piece coupling so that the 32 windings are connected parallel. Each side of the winding packs are insulated with two layers of plastic on both sides. The capacitors are filled with $SF_6$ gas.

**Test C1**

The outside of C1 was in good condition, but it showed a very high capacity drop. [...] The test did not find any problem or damage to the insulation or the internal structure, and the $SF_6$ gas was still in the capacitor.

The capacity values of the windings were between ~ 2 nF and 59 µF, but the distribution was uneven: most units were in the upper (40 - 60 µF), or lower (2 - 40 nF) range. One winding had melted slightly in several places and was not measureable anymore.

Each winding showed large numbers of self-healing marks, some of which were fairly large. In the low-capacity windings, the majority of the self-healing marks were large, and there were several large self-healing marks in the molten winding which showed punctures through several film layers. The self-healing marks were denser on one side of the film, asymmetrically.

**Test C2**

The C2 capacitor was deformed in several places, and it was also dented, but the capacitor body did not open. The insulation between the windings and the house melted in several places and was partially carbonised. A couple of windings in the middle melted, and a big hole was formed.

The film from the C2 windings shows a lot of self-healing marks in both the flat and the round areas. Such self-healing marks were present in both rows, but there were much more of them in one row than in the other; almost all safety elements of the segmentation were fused at the side which showed the worse damage.

**Figure 3: The state of the C2 capacitor**

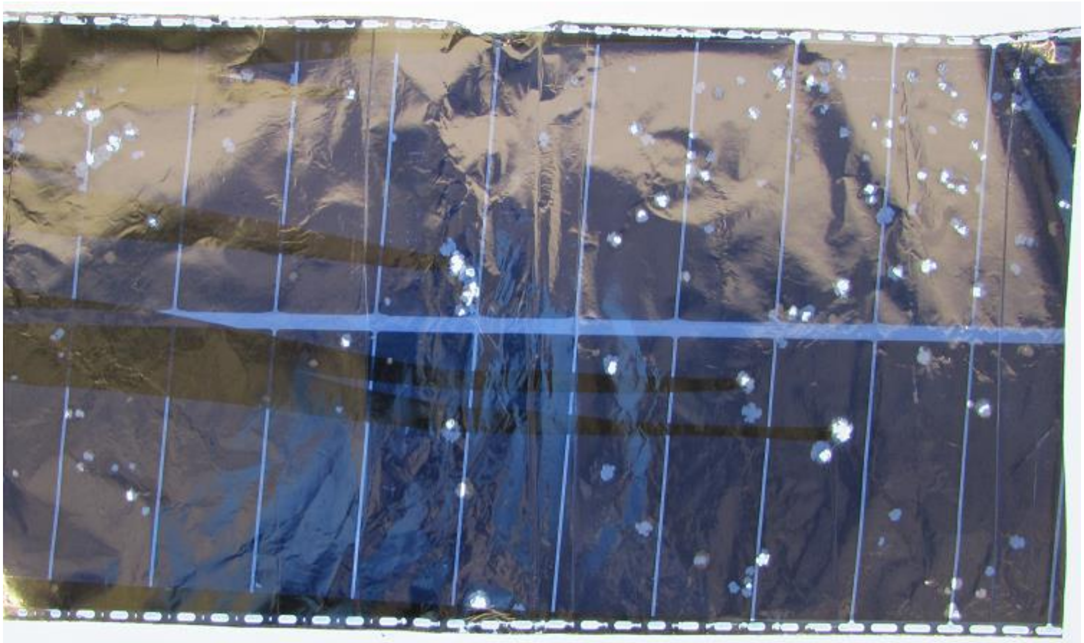

**Figure 4: Capacitor film with marks of self-healing**

### Tests C3 and C4

Both C3 and C4 were in good condition, both inside and outside. [...] The measurements on each winding showed similar values than on C1, but overall there were fewer units within the nF capacity range. There were a lot of self-healing marks in all windings.

**Summary**

The combustible gases were released when the polypropylene parts of C2 melted. According to estimation, 325 $cm^3$, i.e. approx. 307 g of polypropylene melted in the case concerned and, according to theoretical calculations, the process produced approx. 15 $dm^3$ gas.

The melting of the capacitor's circuits may have been caused by the voltage increase due to a particularly high number of self-healings and the loss of the safety function of segmentation. In parts with more leaks, the internal serial connection may have resulted in an avalanche effect. The reason for this is that when the value of a serial capacity is suddenly reduced, then the related voltage will rise. Because of higher voltage, new holes form, and in turn, voltage will continue to rise. This process took place fully for all windings in each nF-capacity range. As a result, the total voltage in the serial capacity was present over a longer period of time, which corresponds to twice the planned voltage load.

The progress of perforation at the time of occurrence of double voltage and high-energy field in each winding was such that a puncture process in one of the windings had not even been completed yet when another one had already started on the film layer of the next winding. This led to melting of the polypropylene insulation, which the segmented design could no longer prevent, i.e. segmentation was probably unable to perform its function.

Experience shows that perforation occurs only to very low extent in metallised film capacitors under normal operating conditions even in 15 to 20 years and therefore no satisfactory answer has been given to the issue of the increased occurrence of perforation in this case. It is observed that the perforations occur to a greater extent at the end of the lifetime, but the capacitors tested are not even close to the end of their lifetimes according to the datasheet. Their failure could have been caused by some other problem(s). It is assumed that the reason(s) may be as follows:

- poor quality of the metal film layer built into the capacitor,
- the technology used for the drying and tempering of the capacitor was not appropriate, or
- the technology used for the winding-up of capacitor liner is not appropriate, or
- possibly the capacitor was overloaded due to operating conditions (overvoltage).

In view of the fact that the same degree of perforation and a similar decrease in capacity was observed in capacitors produced by the producer during the same period but with a film layer other than the film layer used for the capacitors concerned, the fault probably lies in the manufacturing technology used at that time.