Pilot project for the demonstration, testing and approval of the digital automatic coupler for rail freight traffic

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Interim Report: Completion of Phase I

Phase I – Summary and Presentation of Results

Federal Ministry for Digital and Transport

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DB ermewa GATX Rail Cargo Group SBB Cargo VTG

Foreword

The DAC4EU consortium (DAC4EU = Digital Automatic Coupler for Europe), consisting of the consortium leader DB AG, the freight railways DB Cargo AG, Rail Cargo Austria AG and SBB Cargo AG as well as the wagon keepers Ermewa SA, GATX Rail Europe GmbH and VTG Rail Europe GmbH, completed Phase I practical testing of the digital automatic couplers (DAC) on 30 June 2021. The project is being carried out on behalf of the Federal Ministry of Transport and Digital Infrastructure (BMVI) between June 2020 and December 2022 and received around EUR 13 million in financing. The pilot project is intended to provide a foundation of technical data that will enable a Europe-wide migration to a DAC Type 4 to be implemented by 2030. The aim of Phase I was to carry out targeted individual tests in controlled environmental conditions that would make it possible to compare the performance of different coupler systems. These included coupling and running tests in different track geometries, at different speeds and load states as well as climate chamber tests under different climatic conditions. The investigations focused on both the mechanical behaviour of the coupler designs and the electrical properties of the electric couplers for the transmission of power and data.

To mark the completion of Phase I, a report has been prepared describing the work carried out in the relevant work packages 1 and 2 of the project and presenting the test results. The test results show, on the one hand, the functionality of the DAC prototypically developed by the various manufacturers and, on the other hand, can be used as a basis for further technical development. This document contains a summary of the testing procedures and their results. Six separate documents prepared by DB Systemtechnik are included as annexes. These contain the detailed test reports including measurement graphs and evaluations of the results. The following document refers to these annexes for further details. The reports are divided into six sections:

1. Measuring Equipment

2. Coupling and running tests

3. Derailment tests and longitudinal compressive forces

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1. Summary

During the nine-months “Phase I”, detailed tests were carried out on four different DAC Type 4 prototypes to investigate their mechanical, electrical and pneumatic coupling functions as well as potential systems for power and data communication. A total of 16 DAC prototypes were purchased from four manufacturers for the purpose of testing. These were Scharfenberg / latch type DACs from the manufacturers Dellner and Voith, the DAC with the Schwab coupler head from Faiveley Wabtec and a DAC based on the SA-3 design from CAF[1]. The couplings were each installed in three freight cars and subjected to the contractually agreed test concept of the open and international industrial platform with the participation of the manufacturers. In addition to tests on different track geometries, with different load states and at different speeds, the couplers were tested in a climate chamber and evaluated to demonstrate their safety in the case of derailment in comparison with screw couplers. The consortium assumed that the manufacturers would provide couplers that were ready for use and testing.

In the course of the tests, however, it has been shown that the DAC prototypes did not meet the requirements with regard to technical readiness for use. In agreement with the consortium, Phase I was extended to give the manufacturers sufficient time to carry out the improvements and then test them in the project. Consequently, the original date for the conclusion of testing was moved from February 2021 to June 2021. The two Scharfenberg / latch type prototypes and the Schwab prototype were successively optimised between December 2020 and April 2021 to meet the requirements of the test programme. In some cases, the couplers did not meet the standards required by the original specifications. Here, too, the manufacturers were able to remedy these problems, although by the end of Phase I individual couplers were still unable to meet all the specifications (e.g. diameter of the main brake pipe). To document their development within the project, the individual DAC designs were identified as *Generation 2* (latch type design from Dellner) and *Version 1.2* (Scharfenberg design from Voith and Schwab design from Wabtec) after the respective improvements had been implemented. This will provide transparency for the development of the prototypes even after completion of this project.

In the case of the SA3 coupler design, the suppliers were unable to provide a testable prototype, despite three major and several minor repair attempts by the experts at CAF and Dellner. In May 2021, the SA3 design was removed from the test programme at the request of the manufacturer (Dellner).

[1] Note: CAF's coupler division was acquired by Dellner in spring 2021

Fig. 1 shows the timetable of the overall project with the two test phases for testing.

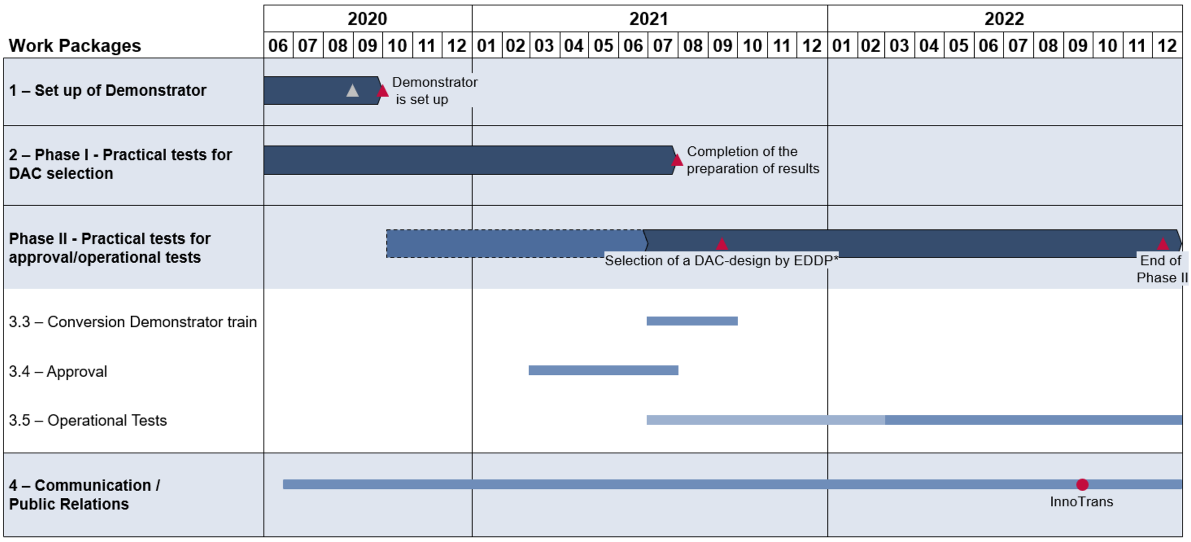

Fig. 1: Timetable for the overall project

The timetable in Fig. 2 shows the progress of Phase I in detail.

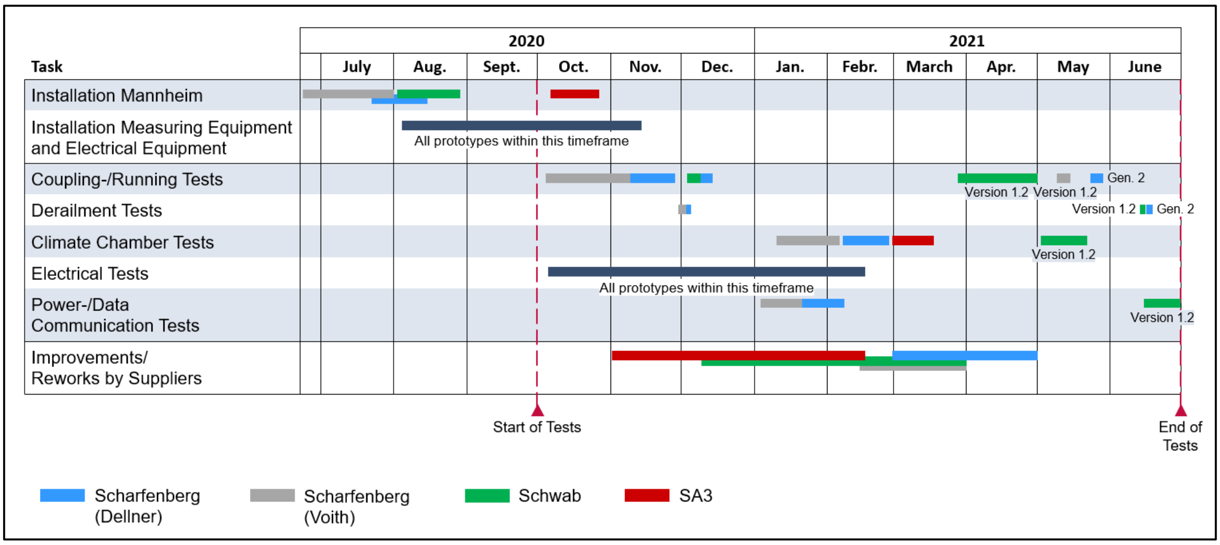

Fig. 2: Timetable for Phase I

The extension of the test phase enabled the planned test scenarios to be fully completed for the three remaining coupler designs. A total of more than 2,500 tests were carried out, of which about 200 were in the climate chamber. Here it was shown that the ability of the designs to couple reliably in slush and ice was a challenge for individual couplers. Detailed, comprehensive results were obtained for three of the four coupler designs, comprising a data volume of over 180 gigabytes.

The processed test results were submitted to the EDDP[2] in July 2021. In the first stage of the coupler selection process, the EDDP held "KO criteria meetings". The test results were also used in the "Basic Requirement Workshops" at the EDDP, where the performance of the couplers was evaluated further and assessed to determine any need for optimisation of the tested designs. Here, the test results provided the foundation for the decision-making process. On 21 September 2021, the EDDP decided to focus on the Scharfenberg / latch type DAC design in its further studies and eliminate the other candidates from the selection process. Based on this decision, further testing in the upcoming Phase II will only be carried out with the Scharfenberg / latch type design.

2. Construction of a Demonstrator (WP 1)

In Work Package 1, the demonstrator train was set up for the test programme by equipping a total of 12 wagons with the DAC prototypes and measurement technology. This chapter describes the selection and configuration process for the wagons as well as the measurement technology used. A more detailed description of the measurement technology can be found in the DB Systemtechnik report in Annex 1.

2.1 Configuration of the Demonstrator

Four groups of wagons, each with three wagon types, were provided for the test programme. These were a four-axle freight wagon (Eanos), a two-axle freight wagon (Hbbins) and a four-axle tank wagon (Zags). The three freight wagon types represent over 265,000 freight wagons out of a total of approx. 685,000 freight wagons registered in the European Vehicle Register ECVVR in Europe. The freight wagons were first prepared for the installation and mounting of the DAC, including power and data lines. The components were assembled and the measurement technology calibrated.

Each of the four wagon groups was then fitted with one of the coupler designs. This made it possible to test each prototype under identical conditions. The wagon groups were connected using screw couplers. Fig. 3 shows the structure of the demonstrator.

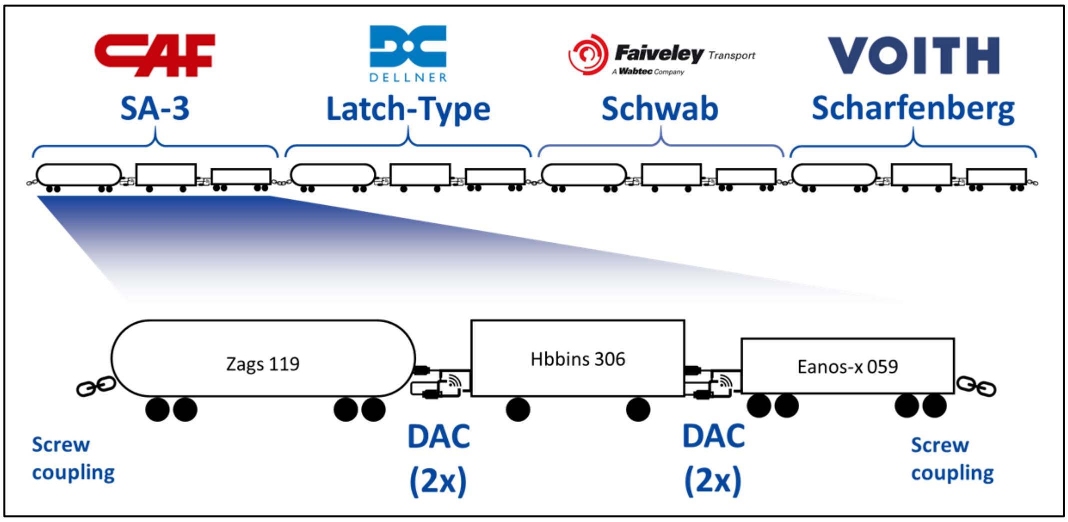

Fig. 3: Configuration of demonstrator Phase I

[2] EDDP – European DAC Delivery Programme of Shift2Rail

2.2 Equipping and Converting the Demonstrator

The couplers were installed at the DB Cargo workshop in Mannheim. Here, a total of 16 DAC prototypes were installed in 12 wagons. Fig. 4 provides an impression of the installation work.

Fig. 4: Installation of the couplers at the DB Cargo plant in Mannheim

For the installation of the couplers, a cooperation agreement was concluded with the freight wagon workshop operated by DB Cargo in Mannheim. This workshop became the central conversion and repair location during the test programme. The cooperation allowed the project to collect and process feedback from employees, which could be used to identify challenges in the installation and conversion process as well as optimisation potential. Subsequently, both coupler heads as well as the wagons and wheelsets were equipped with measurement technology by DB Systemtechnik. For this purpose, connection boxes were mounted on the wagons. This allowed the tests to be carried out with uniform interfaces and significantly reduced the work involved in the installation of electrical wiring in the wagons. The “central connection box” housed all the measuring equipment for power supply and data communication during the tests. It was connected to the "coupler connection boxes" (Fig. 6) via a central cable. This setup was identical for all the wagons. A compact “coupler connection box” was mounted in the area of each coupler. This was used to connect the manufacturers' cable concepts, which were not yet standardised, in a uniform manner in the area of the DAC. By taking this approach, it was possible to work with one main cable on each wagon.

Fig. 5 (below) presents a visualisation of the described concept. Figs. 6 and 7 show the connection boxes mounted on the Zags wagon as an example.

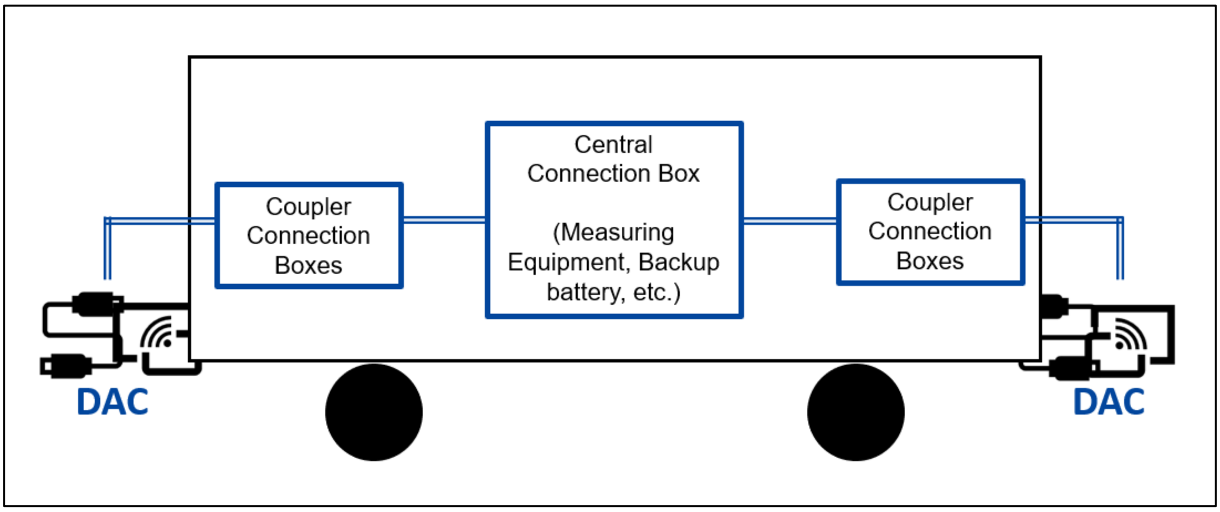

Fig. 5: Installation of measurement technology

Fig. 6: Example of connection box on Zags wagon

Fig. 7: Coupler connection box on the Zags wagon on the side of the screw coupler

The measurement technology implemented on the freight wagons for the Phase I tests can be classified into three categories:

- Measuring instruments for mechanical and pneumatic testing,
- Measurement technology to prove the functionality of the power supply and
- Measurement technology for the investigation of the reliability of data communication.

3. Phase I – Practical Tests for Selection of the DAC (WP 2.1 and WP 2.2)

The tests were carried out by DB Systemtechnik at the TÜV Süd test site in Görlitz and at the DB Systemtechnik site in Minden (climate chamber tests and power/data tests) from October 2020 to June 2021. The basis for carrying out the tests were the functional requirements developed and approved by the TIS (Technischer Innovationskreis Eisenbahngüterverkehr; www.tis.ag), which were to be examined, among other things, within the scope of this project. A comprehensive test plan was developed based on these principles. The test plan was continuously adapted to take account of the discussions that were taking place at the same time at the European level. In this way it was possible to ensure that all requirements for the subsequent selection discussion were checked through the tests. The main focus was on testing the mechanical coupling functions and the air, power and data line connections. An article describing the test concept in detail was also published in ETR Magazine, May 2021 issue.[3]

Each coupler underwent an extensive programme of running and coupling tests, derailment tests under longitudinal compressive forces (also referred to here as derailment tests), climate chamber tests, electrical tests and tests for power and data communication. A detailed test-

[3] Dr.-Ing. Wartzek, Fabian und Dr.-Ing. Jobstfinke, Daniel (2021), "Versuche zur Erprobung der Digitalen Automatischen Kupplung für Europa", ETR, 05/2021, pages 55-60

execution concept was submitted to the BMVI in September 2020. Several tests were accompanied by a film crew who documented the pilot project on film (Fig. 8). This chapter will now discuss how the tests were conducted and present the results. Detailed descriptions of the respective test setups, the implementation of the tests and the results can be found in the respective annexes. The test reports contained therein describe the individual tests in detail and the results are supported by measurement notes, diagrams, photographs, etc.

Fig. 8: April 2021 – Coupling tests with Schwab DAC, shortly before the coupling impact

3.1 Coupling and running tests

The coupling and running tests, together with the derailment tests, were at the heart of the mechanical investigation of the prototypes. A large number of tests at various speeds in different geometries were carried out to demonstrate the coupling capabilities of the designs and verify that they were able to operate with no restrictions. All the necessary track geometries were available in Görlitz in a specially designated area (Fig. 9). To better assess the significance of the results and their repeatability, the experiments were each performed five times. Details can be found in Annex 2.

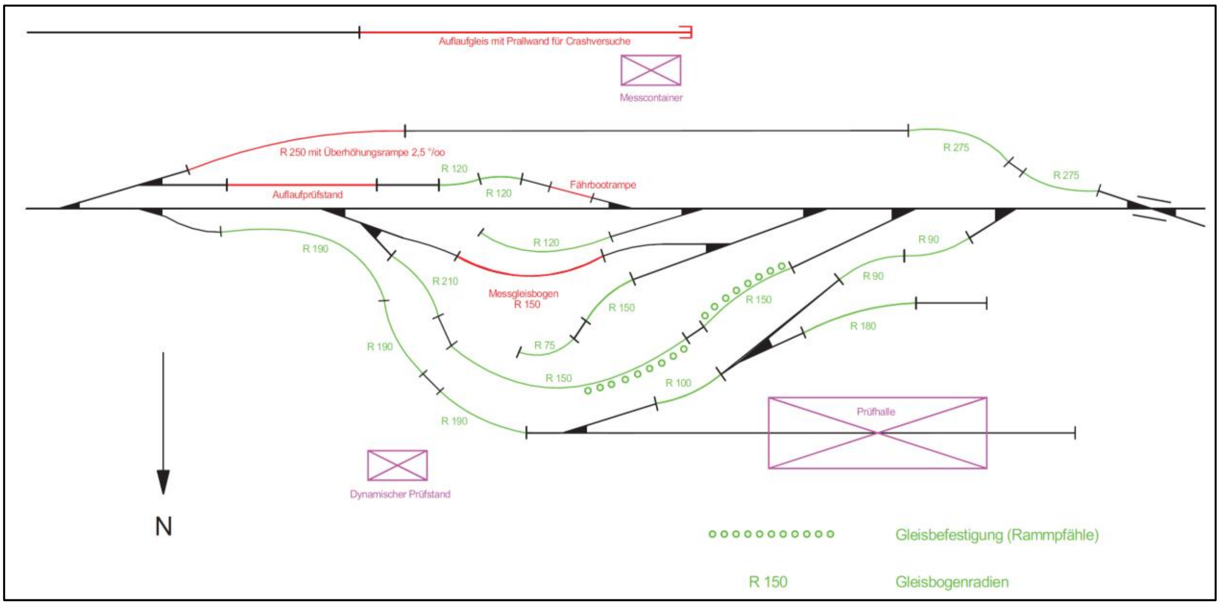

Fig. 9: Track plan of the test facility in Görlitz

3.1.1 Implementation

In addition to testing the prototypes with different speeds and track geometries, tests were also carried out in different load conditions (Table 1-3). These were designed to test the couplers under all possible extreme settings. The load condition influences the vertical height offset while also changing the forces acting on the couplers. Tests in different bend geometries made it possible to specifically evaluate the influence of a changing lateral offset. In addition, the ability of the wagons to run on certain track geometries was tested with the coupler prototypes in the coupled state. The wagons were alternately pulled and pushed through the geometries.

During the running tests, the mechanical coupling performance of the DACs was evaluated in accordance with two criteria. Firstly, a permanent mechanical, pneumatic and electrical connection between the DACs (no separation) and, secondly, the ability to run on the respective track geometry without restrictions.

Explanation of Table 1-3:

Running tests with a coupled three-wagon group

The coupling point to be evaluated in the coupling tests is located between the wagons marked in blue

Table 1: Load Condition 1 “full - empty - empty”

					Speed [km/h]							
Spec-No.	Infrastructure	Eanos	Hbbins	Zagns	2	4	6	8	10	12	Drive	No. test-drives
3.1	straight track	full	empty	empty	5	5	5	5	5	5		
3.2	curved track R 190m	full	empty	empty	5	5	5	5				
4.1	curved track R 190m	full	empty	empty							pulled	5
4.2	curved track R 190m	full	empty	empty							pushed	5
3.3	curved track R 150m	full	empty	empty	5	5	5	5				
4.3	curved track R 150m	full	empty	empty							pulled	5
4.4	curved track R 150m	full	empty	empty							pushed	5
3.4	S-curve 190m	full	empty	empty	5	5						
4.5	S-curve 190m	full	empty	empty							pulled	5
4.6	S-curve 190m	full	empty	empty							pushed	5
3.6	S-curve 150m, with 6m intermediate straight	full	empty	empty	5	5						
4.9	S-curve 150m, with 6m intermediate straight	full	empty	empty							pulled	5
4.10	S-curve 150m, with 6m intermediate straight	full	empty	empty							pushed	5
4.11	curved track R 100m	full	empty	empty							pulled	5
4.12	curved track R 100m	full	empty	empty							pushed	5
4.13	curved track R 75m	full	empty	empty							pulled	5
		full	empty	empty							pushed	5
4.14	Ramp with 2°30´ pitch	full	empty	empty							pulled	5
4.15	Ramp with 2°30´ pitch	full	empty	empty							pushed	5

Table 2: Load Condition 2 "full - half-full - empty”

					Speed [km/h]							
Spec-No.	Infrastructure	Eanos	Hbbins	Zagns	2	4	6	8	10	12	Drive	No. test-drives
3.1	straight track	full	partly	empty	5	5	5	5	5	5		

Table 3: Load Condition 3 “full - full - empty”

					Speed [km/h]							
Spec-No.	Infrastructure	Eanos	Hbbins	Zagns	2	4	6	8	10	12	Drive	No. test-drives
3.1	straight track	full	full	empty	5	5	5	5	5	5		
3.2	straigh track	full	full	empty	5	5	5	5	5	5		
3.2	curved track R 190m	full	full	empty	5	5	5	5				
3.3	curved track R 191m	full	full	empty	5	5	5	5				
4.1	curved track R 190m	full	full	empty							pulled	5
4.2	curved track R 190m	full	full	empty							pushed	5
3.3	curved track R 150m	full	full	empty	5	5	5	5				
3.4	curved track R 151m	full	full	empty	5	5	5	5				
4.3	curved track R 150m	full	full	empty							pulled	5
4.4	curved track R 150m	full	full	empty							pushed	5
3.4	S-curve 190m	full	full	empty	5	5						
3.5	S-curve 191m	full	full	empty	5	5						
4.5	S-curve 190m	full	full	empty							pulled	5
4.6	S-curve 190m	full	full	empty							pushed	5
3.6	S-curve 150m, with 6m intermediate straight	full	full	empty	5	5						
3.7	S-curve 150m, with 6m intermediate straight	full	full	empty	5	5						
4.9	S-curve 150m, with 6m intermediate straight	full	ful	empty							pulled	5
4.10	S-curve 150m, with 6m intermediate straight	full	full	empty							pushed	5
4.11	curved track R 100m	full	full	empty							pulled	5
4.12	curved track R 100m	full	full	empty							pushed	5
4.13	curved track R 75m	full	full	empty							pulled	5
		full	full	empty							pushed	5
4.14	Ramp with 2°30´ pitch	full	full	empty							pulled	5
4.15	Ramp with 2°30´ pitch	full	full	empty							pushed	5

3.1.2 Results

There were significant differences in the results of the coupling and running tests of the tested prototypes from Voith, Dellner and Wabtec. Deficiencies and weaknesses were identified in the couplers from all the manufacturers during the tests and all the coupler designs required improvements. As already explained, it would not have been possible to produce the comprehensive database for all prototypes in the test without the extension of the testing period and remedial work on the designs by the manufacturers. The following section considers the three DAC designs individually and summarises the findings for each design. The precise evaluations can be found in the DB Systemtechnik test report in Annex 2.

- Scharfenberg-type coupler from the manufacturer Voith

Coupling procedures with Version 1 of the Voith DAC failed in many cases. This behaviour was observed and reproducible particularly at speeds of 6 km/h (18 of 72 tests unsuccessful) and 8 km/h (11 of 58 tests unsuccessful). After the initial tests in 2020, some tests were repeated in 2021 following the completion of climate chamber testing. In cases where the mechanical coupling process was successful, the pneumatic coupling process was also successful.

Electrical coupling operations were evaluated as "unsuccessful" in many cases (e.g. 24 of 72 attempts unsuccessful at 6 km/h). Externally, the contacts often showed clear signs of wear after only a few attempts. In many cases, the failure of individual contacts due to this wear pattern was the cause of the negative result of the evaluation. The contacts were not repaired, so after the initial damage was sustained all subsequent attempts at coupling the electrical lines were also identified as faulty. A detailed inspection showed that only a few contacts failed permanently.

Voith developed and supplied a version 1.2 with an adapted coupler head. During the coupling tests with the second version of the DAC design, mechanical coupling failures no longer occurred at the aforementioned low and medium speeds. Only during coupling tests at 12 km/h did the wagons bounce off each other twice without coupling. The problems with the contacts in the electrical coupler were unchanged in this version of the DAC.

During the coupling tests in 2020, a valve broke in the main brake pipe. This occurred repeatedly during the tests in 2021. To enable the tests to continue, the new valve housings were additionally secured with tensioning belts from the outset. Voith worked on a reinforced version, but this could not be made available in time for the Phase I trials.

The running tests with Version 1 of Voith's Scharfenberg design were generally completed without any problems. All infrastructures could be used without restrictions.

- Latch type coupler from the manufacturer Dellner

The first generation of Dellner's latch type design did not meet the required mechanical strength requirements, so Dellner placed a limit on the permissible coupling impact with its prototypes. Specifically, coupling impacts at speeds over 10 km/h were prohibited. With this first tested generation, the tests of the mechanical and pneumatic connections during coupling operations were 100% successful.

The second generation coupler included a mechanical upgrade to the DAC and the implementation of a stabilisation joint. Except in the derailment tests, Generation 2 was tested in only a few of the coupling test configurations (22 tests at 2 km/h; 7 tests at 6 km/h; 11 tests at 8 km/h; 1 test at 10 km/h and 8 tests at 12 km/h). There was only one failed coupling attempt between the Z- and H-wagon on the straight track. For organisational reasons, the coupling tests at 0.6 km/h, which were only specified during the project, could only be carried out for Generation 2 without the compressed air supply (7 tests in total). For this reason, it was not possible to evaluate the pneumatic coupler here. In the coupling tests at the other speeds, however, there were no abnormalities in the pneumatic coupler. Thus, it can also be assumed to function safely in this case.

The electrical coupling operations were evaluated as “unsuccessful” in many cases (e.g. 27 of 27 attempts unsuccessful at 2 km/h). Externally, the contacts often exhibited clear signs of wear and the moving side of the contact jammed after only a few attempts. In many cases, analogous to the results of the Voith coupler, the failure of individual contacts was the cause of the negative evaluation result. In at least one case, however, the two electrical couplers missed each other entirely.

The running tests with Generation 1 of the latch type DAC by Dellner were generally completed without any problems. All infrastructures could be used without restrictions. The evaluation did show errors in the electrical coupler in many cases (electrical coupling unsuccessful in 127 of 154 attempts). However, this was most likely caused by damage to the electrical coupler contacts during previous coupling attempts.

- Schwab-type coupler from the manufacturer Wabtec:

Initial tests with the Wabtec coupling resulted in serious damage to two couplers during coupling tests at low speeds (4 km/h) on a straight track (Fig. 10).

Fig. 10: Broken Schwab design coupler heads

Wabtec then provided the previous version of the broken DAC, which was installed and used for the tests. This previous version was much more robustly constructed and, in contrast to the damaged version, was divided into two parts. With the tested DAC prototypes, the tests of the mechanical connections during coupling operations were 100% successful. Pneumatic coupling operations failed in several cases (e.g. 12 of 104 attempts unsuccessful at 2 km/h). Coupling Zags and Hbbins was only partially possible in the 100-meter curved track and depended on the load state of the Hbbins wagon. It was not possible to couple Zags and Hbbins in the 75-metre curved track. During the tests, design weaknesses appeared in the moving parts of the electrical contact coupler. As a result, the majority tests for the electrical connection were listed in the logs as not successfully closed (e.g. 48 of 104 tests unsuccessful at 2 km/h). Selected follow-up tests have been carried out with the retrofitted e-couplers. Only a limited speed range could be examined. In these follow-up tests, the measurements taken were successful. There were no significant signs of wear on the e-contacts.

The mechanical and electrical aspects of the running tests were 100% successful. However, problems were identified with the pneumatic connection (pneumatic coupling was unsuccessful in 30 of 142 tests). Air leaks briefly occurred here. The brakes were deactivated to prevent them from influencing the tests, so it was not possible to consider any effect on the control valve. In addition, the tests aimed to detect even small leaks, so the locomotive did not refill the air line during the tests.

During the tests, it became apparent that the force required to separate two uncoupled wagons was steadily increasing. Towards the end of the tests, two uncoupled wagons could only be separated if the rear wagon was immobilised and the front wagon pulled away by a locomotive. For the very last tests, Wabtec was able to rectify this problem by deflecting the coupler heads sideways using an adapter on the coupling rod. This seemed to bring the uncoupling force back into an acceptable range. However, this could not be tested sufficiently due to a lack of time.

3.2 Derailment tests under longitudinal compressive forces

In addition to the coupling and running tests, the mechanical tests also included tests in which the wagons were pushed to investigate derailment safety. These derailment tests were carried out by DB Systemtechnik on two-axle Hbbins 306 freight wagons, which were equipped with a DAC at both ends of the wagon. The wagons were fitted with special measuring equipment to measure, among other things, the vertical lift of the four wheels, the contact force and the lateral force.

The aim of the tests was to determine the tolerable longitudinal compressive forces up to the level of assessment criteria according to UIC 530-2[4] and the limit criterion according to DIN EN 15839[5]. The following values were used as assessment or limit criteria during the tests:

(1) a specified maximum permissible vertical lift of a non-guiding wheel, or

(2) a maximum permissible lateral force for the wheelset bearing

In UIC 530-2, 500 kN is defined as the mandatory and 600 kN as the recommended target value for the tolerable longitudinal compressive force for wagons with automatic couplers.

The following section provides a general description of the testing procedure and a summary of the main findings. A detailed version can be found in Annex 3.

[4] UIC 530-2: Railway applications – Freight wagons – Running safety, 5th edition, December 2005

[5] DIN EN 15839: Railway applications – Testing for the acceptance of running characteristics of railway vehicles – Freight wagons – Testing of running safety under longitudinal compressive forces; English version EN 15839:2012+A1:2015

3.2.1 Implementation

The tests were carried out in the 150 m S-curve with 6 m intermediate straight. Fig. 11 shows the track geometry for the test. The test object was the Hbbins wagon in the middle of the three-wagon configuration. It is well known that two-axle wagons are the most prone to derailment in such tests. The adjacent Eanos and Zags wagons were fully loaded. The group of wagons was pushed during the test with the brake wagons coupled in front of the wagons to enable the test forces to be applied by the locomotives coupled at the rear. The configuration is shown in Fig. 12.

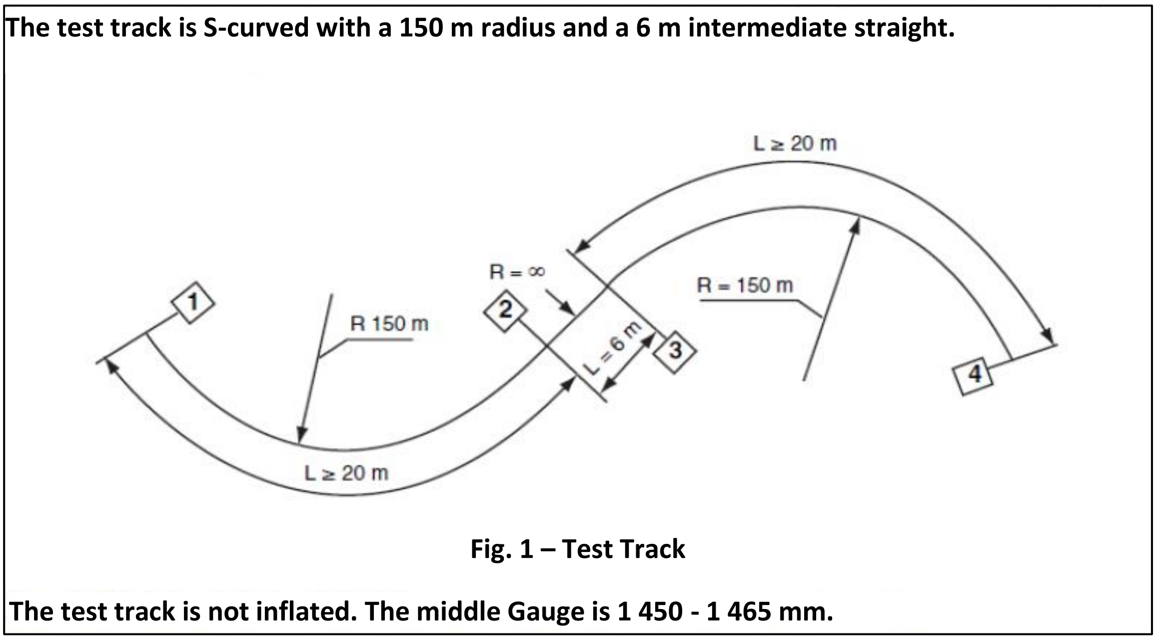

Fig. 11: Track geometry for derailment tests[6]

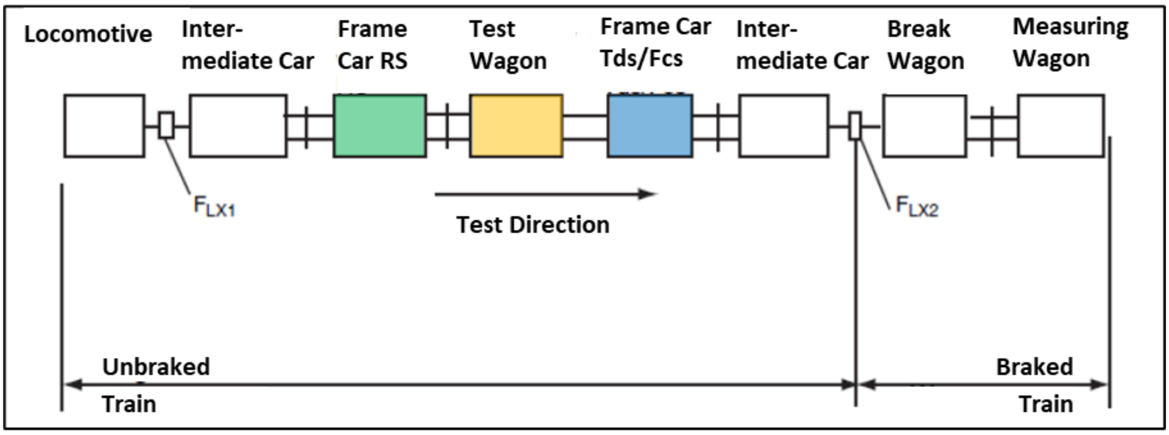

Fig. 12: Schematic diagram of the derailment tests[7]

[6] Source: UIC Leaflet 530-2, Freight wagons - Running safety, 7th edition, December 2011

[7] Source: UIC Leaflet 530-2, Freight wagons - Running safety, 7th edition, December 2011

In accordance with the specifications of the UIC Code and in order to identify the limits of the couplers, the longitudinal force was increased incrementally, starting at a level of 100 kN. The following variables were measured:

- Longitudinal compressive force F_{Lxi}
- Wheel lift $d_{zij\ an}$ for all wheels
- Lateral forces on wheelset bearings H_{yj} for all wheelsets
- Distance (e.g. 1 m mark)

The transverse displacement of buffers measured in tests with screw couplers is not applicable in tests with DACs. The distance is calculated indirectly by integrating the measured speed.

3.2.2 Results

In the derailment tests, none of the couplers fell below the minimum value of 200 kN for the tolerable longitudinal compressive force required for a screw coupler. With the exception of the first generation of latch type couplers from Dellner, all the couplers significantly exceeded the reference level of the screw coupler (in some cases by a factor of more than 2). A comparison of the maximum forces for the individual designs is shown in Fig. 13. It should be noted that the two Scharfenberg / latch type designs derailed at the stated values, while the tests for the Schwab design were stopped at the stated value, since a significant wheel reaction had already occurred and the manufacturer had instructed the test team to avoid a derailment. In addition, none of the couplers reached or exceeded the limit values for wheel lift and the maximum permissible lateral force on the wheelset bearings.

DIN EN 15839 defines the maximum permissible vertical lift for a non-guiding wheel as 50 mm. Despite not reaching the limit value for wheelset lift, derailments occurred during the tests. The reasons for this could not be conclusively determined and could be the subject of further research.

The UIC 530-2 states a nominal maximum force of 200 kN. A surcharge of 10% is relevant for trials. The nominal value for the maximum strength is valid without a 10% surcharge. The target values specified in UIC 530-2 for the tolerable longitudinal compressive forces for wagons with automatic couplers (500 kN = mandatory target value; 600 kN = recommended target value) could not be achieved or exceeded by any coupler. However, it has not yet been finally determined whether the target values for the tolerable longitudinal compressive force in accordance with UIC 530-2 are applicable to the derailment tests and coupler prototypes described here. Nevertheless, the data base resulting from the tests could be essential for making further progress towards gaining European approval.

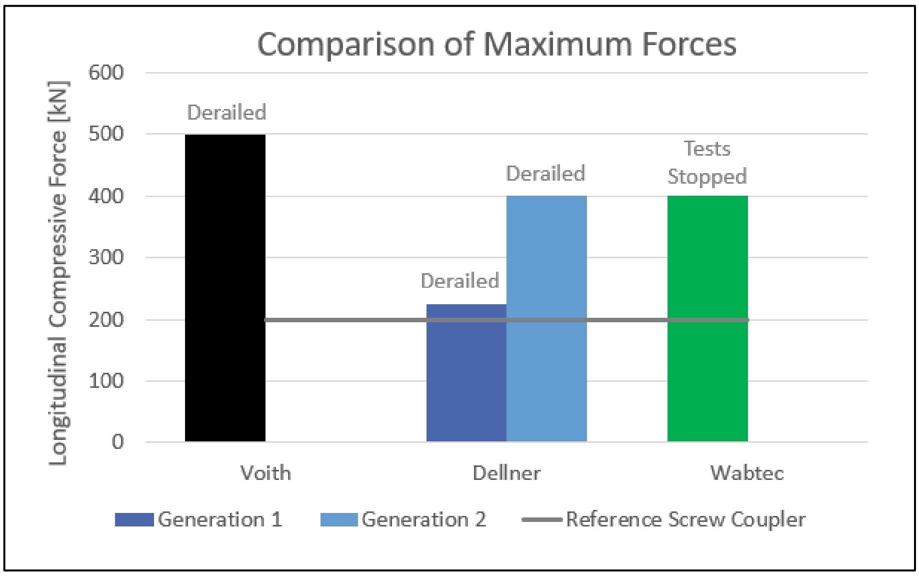

Fig. 13: Comparison of the maximum longitudinal compressive forces achieved with the DAC prototypes

The following section considers the three DAC designs individually and summarises the findings for each design. The detailed evaluations can be found in Annex 3 of the DB Systemtechnik test report.

- Scharfenberg-type coupler manufactured by Voith

On one occasion, the Scharfenberg-type DAC from Voith tolerated a nominal maximum longitudinal compressive force of 475 kN before derailing during a test in which this force was increased further. The tolerable longitudinal compressive force for the Hbbins 306 wagon with the Scharfenberg DAC was thus above the minimum value of 200 kN for two-axle wagons with screw couplers and side buffers. The limit value for wheel lift was not achieved or exceeded in any of the valid tests; it was approx. 9 mm.

- Latch type coupler manufactured by Dellner

The latch type DAC from Dellner tolerated one test with a nominal maximum longitudinal compressive force of 225 kN. A repeat attempt resulted in derailment and the test continuation was aborted. The tolerable longitudinal compressive force for the Hbbins 306 wagon with the latch type DAC was above the minimum value of 200 kN for two-axle wagons with screw couplers and side buffers. The limit value for wheel lift was not achieved or exceeded in any of the valid tests; it was approx. 6 mm.

In contrast to the first generation, a stabilisation joint was implemented on the second generation of the latch type DAC from Dellner. A stabilisation joint increases the coupler's tolerance of longitudinal compressive forces. On one occasion, the second generation latch type DAC from Dellner tolerated a nominal maximum longitudinal compressive force of 400 kN before derailing during a test in which this force was increased further. The tolerable longitudinal compressive force for the Hbbins 306 wagon with the Dellner DAC was thus above the minimum value of 200 kN for two-axle wagons with screw couplers and side buffers. The limit value for wheel lift was not achieved or exceeded in any of the valid tests; it was approx. 6 mm.

- Schwab-type coupler manufactured by Wabtec

The Schwab DAC from Wabtec tolerated one test with a nominal maximum longitudinal compressive force of 400 kN. In consultation with the manufacturer, the test team decided not to carry out any tests with higher forces in order to avoid the risk of derailment. At 400 kN, the tolerable longitudinal compressive force for the Hbbins 306 wagon with the Schwab DAC was above the minimum value of 200 kN for two-axle wagons with screw couplers and side buffers. The limit value for wheel lift was not achieved in any of the other confirmation tests; it was max. 6 mm.

3.3 Climate chamber tests

Coupling and uncoupling tests were carried out under various ambient conditions and temperatures in the climate chamber operated by DB Systemtechnik GmbH in Minden (see Fig. 14) with the prototypes of the two Scharfenberg / latch type and the Schwab designs. These tests aimed to determine whether the couplers functioned properly in extreme climatic situations. The mechanical, pneumatic and electrical connections were also examined during the climate chamber tests. The tests investigated both the uncoupling behaviour of a connected coupling point under climatic control and the coupling behaviour of two coupler heads under independent climatic control. The uncoupling problems experienced with the Schwab prototype made it impossible to investigate its uncoupling behaviour further in the climate chamber.

Temperature	Condition	No. Of tests
45°C	dry air	5
45°C	90% humidity	5
0°C	wet snow	5
-5°C	wet snow	5
-10°C	dry air	5
-10°C	3-5 mm ice on coupler face DAC (coupled)	5
-25°C	dry	5
-25°C	3-5 mm ice on coupler face DAC (coupled)	5

Fig. 14: Conditions for climate chamber tests

During the tests, the wagons were in the following load conditions (load condition 1):

o Eanos wagon: fully loaded

o Hbbins wagon: empty

o Zags wagon: empty.

The situation in which two light (unloaded) wagons coupled without height offset in icy conditions (in this case the Zags wagon with the Hbbins wagon) was considered the critical case.

3.3.1 Implementation

Before the actual test was carried out, the wagons were exposed to the temperature and ambient conditions selected in the climate chamber for a period of time sufficient to ensure that the components being tested were at a uniform temperature. In the initial situation, the Eanos and Hbbins wagons were positioned in the climate chamber in a coupled state. The Eanos wagon was prevented from moving using stop blocks. The Zags wagon stood in the climate chamber and was not coupled. The H-wagon was then uncoupled from the E-wagon, pushed into the middle by hand and prevented from moving by a stop block. The Zags wagon was pushed onto the still uncoupled side of the Hbbins wagon at approx. 2 to 5 km/h and a coupling process carried out between the Zags and Hbbins wagons. To check the connection of the main brake pipe, the H- and E-wagons were also coupled together again. The diagram in Fig. 15 shows the individual steps.

With the Schwab design, the procedure had to be modified because the uncoupled couplers between the E- and H-wagons could not be pulled apart by hand. This is described in detail in Annex 4 of the DB Systemtechnik test report.

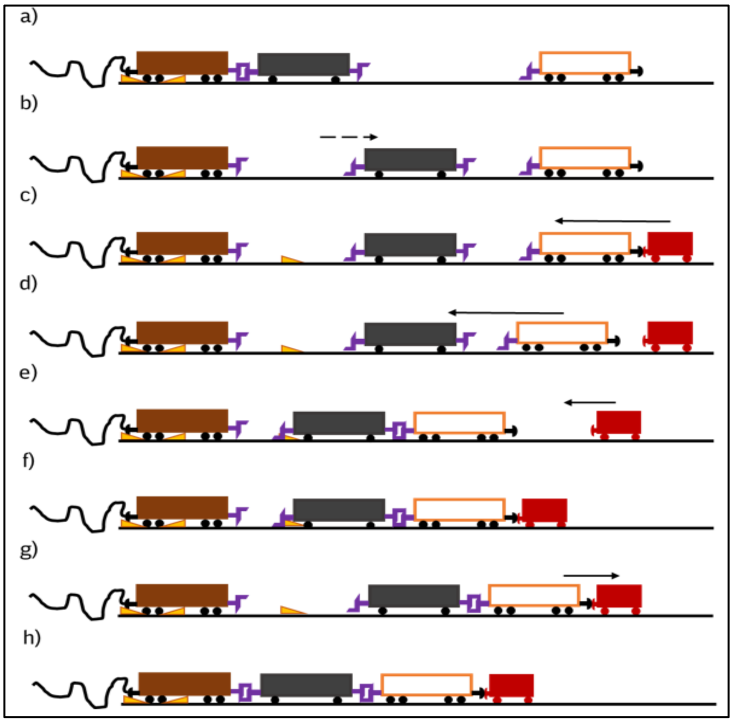

Fig. 15: Schematic diagram of the climate chamber tests

3.3.2 Results

The results of the climate chamber tests indicated that all three DAC prototypes had problems coupling in slush (latch type design from Dellner) and/or ice (all three designs). Above all, the E-couplers were barely able or entirely unable to couple, because the cover flaps and contacts were unsuitable for these weather conditions. In addition, mechanical coupling of the prototypes was not always successful in test runs in slush, snow and/or ice, with Voith's Scharfenberg design achieving the best results. However, this DAC prototype experienced problems during pneumatic coupling, as the necessary pressure build-up was not achieved. A leak in the main brake pipe was suspected but could not be located. In pneumatic coupling, Dellner's latch type design performed best because the pneumatic connection functioned correctly whenever mechanical coupling was successful. Further details and analyses of these results can also be found in Annex 4.

With the Schwab design from Wabtec, as previously explained, it was necessary to deviate from the regular test setup because the couplers between the E- and H-wagons could not be separated manually when uncoupled. A stronger tractive force was required so the H-wagon was positioned freestanding in the initial position. The Schwab prototype could mechanically couple in snow, but not in ice. The pneumatic and electrical connections could only be established at +45°C. For further details, see Annex 4.

3.4 Electrical tests

Each of the four DAC prototypes was equipped with an electrical coupler (E-coupler). In the Schwab and SA3 designs, the E-couplers were each mounted below the mechanical coupler, while they were mounted above the mechanical coupler in the two Scharfenberg / latch type designs. Both the SA3 and the two Scharfenberg / latch type DACs had fixed/spring contacts. The Schwab DAC had pin/socket contacts. A separate test concept was also used to test the functionalities of the E-couplers (power supply, EP brake, transmission of data). Another report produced by DB Systemtechnik describes each E-coupler design in detail as well as the tests carried out (see Annex 5). The main points are listed below.

3.4.1 Implementation

A total of four measurements were carried out: (1) contact resistance measurement, (2) insulation resistance measurement, (3) power transmission through the train, and (4) charging and discharging behaviour of the batteries. The contact resistance and the insulation resistance measurements were carried out before testing of the mechanical coupler began and continued both during and after the test programme. In (1), the DAC prototypes were in a coupled state, while in (2) they were in an uncoupled state. The power transmission (3) was measured for each coupler design in the 3-wagon set and in the coupled state. The charging and discharging behaviour of the batteries (4), on the other hand, was tested in the entire train set with nine wagons. [8]

3.4.2 Results

The Scharfenberg / latch type and Schwab DAC prototypes only partially fulfilled the acceptance criteria for the contact resistance measurements. This was because the maximum resistances were only partially met for the power supply and data lines (for the latch type design from Dellner) or only for the data lines (for the Scharfenberg design from Voith and for the Schwab design).

The insulation resistances of Voith's Scharfenberg design were too low and could “lead to undesired tripping of the insulation monitoring device” during operation.[9] Thus, the E-couplers of this prototype did not meet the acceptance criteria. Details of the measurements and evaluations can also be found in Annex 5.

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[8] Measurements were only made for the Schwab and the two Scharfenberg / latch type designs, as the SA3 model had already been withdrawn by Dellner by that point.
[9] see Annex 5: DB Systemtechnik: Test report – Electrical tests, Chapter 4.4, page 16

On the other hand, the acceptance criteria of (3) and (4) were met by all the E-coupler designs, meaning that “the power was transmitted without restrictions over the test period”[10] and that “the practical function test for the electrical supply was passed.”[11]

Table 4 shows the results of the measurements:

Table 4: Summary of the results

E-coupler	**E11 Contact resistances**	**E12 Insulation resistances**	**E15 Power transmission**	**E16 Charging and discharging behaviour of the batteries**
CAF	Not fulfilled	Fulfilled; (without final measurement)	Not tested	Not tested
Dellner	Partially fulfilled	Fulfilled	Fulfilled	Fulfilled
Voith	Partially fulfilled	Not fulfilled	Fulfilled	Fulfilled
Wabtec	Partially fulfilled	Fulfilled except for 1 contact point; only partial final measurement	Fulfilled	Fulfilled

3.5 Power and data communication tests

An essential feature of a DAC is its ability to provide a power and data connection between the wagons. Three different communication systems were tested within the framework of the project:

- a data transmission system that was integrated into the power lines: Powerline PLUS,
- a wireless technology for communication between the wagons: Wireless LAN and
- a 2-wire solution via separate lines: CAN-FD.

The demonstrator was equipped with the appropriate technology by OWITA on behalf of DB Systemtechnik. In Annex 6, OWITA presents the results in a detailed test report. The main points are listed below.

The aim of the power and data communication tests in Phase I was to select a suitable communication topology for the operational tests in Phase II. The tests showed that all three communication systems are suitable for further evaluation in Phase II. Since the Phase I measurements were carried out in stationery vehicles, the tests in Phase II will focus on testing these systems in moving vehicles. This will deliver further key results for the selection of a communication system for regular operation. The flow of power and data was investigated both in the individual wagon groups and in the full train set of 12 wagons. The connection to the wagon group was bypassed with the SA3 design. No dependence on the coupler design could be determined during the measurements in the individual wagon groups. In the train set, the

[10] see Annex 5: DB Systemtechnik: Test report – Electrical tests, Chapter 5.4, page 20
[11] see Annex 5: DB Systemtechnik: Test report – Electrical tests, Chapter 6.4, page 27

communication systems were tested for resilience and immunity to interference. Communication was shown to be stable.

4. Conclusion

The tests were successfully completed at the TÜV Süd Rail GmbH test site in Görlitz on 30 June 2021. After the originally planned duration of the tests was extended by 4 months, to give the manufacturers sufficient time to make improvements, the contractually agreed test programme for the three remaining prototypes was completed in full. The manufacturer responsible for the SA3-type DAC – Dellner – decided not to carry out any remedial work on the design to make it suitable for testing and removed it from the programme.

Subsequently, the power/data communication tests were also completed. Both the electrical properties of the couplers and their data transmission performance across the wagons were investigated. To do this, tests were carried out on the individual couplers, wagon groups and the entire train. This provided a comprehensive database for the three designs (Scharfenberg / latch type from Voith and Dellner, as well as Schwab from Faiveley Wabtec), with a large number of measured values documenting their behaviour in different load conditions, speeds and track geometries. In addition, the test programme provided measurements and findings on the behaviour of the couplers under different climatic conditions as well as data verifying their derailment safety.

4.1 Use of data in the EDDP

Following the tests, the data were extensively analysed and transferred into a standardised format for submission to the EDDP. The EDDP is a body established by Shift2Rail with the aim of modernising rail freight transport in Europe through the introduction of a standardised DAC solution. The EDDP brings together a wide range of stakeholders with the aim of ensuring an efficient and cost-effective introduction of a DAC. Participants include, among others, various railway undertakings, infrastructure managers, wagon keepers, research institutes and industry organisations as well as political institutions.

The data from the tests in the DAC4EU project were presented at three workshops in July 2021. Here, the pre-defined KO criteria for each coupler design were presented and evaluated. Based on data provided by DAC4EU and others, the EDDP voted in favour of the Scharfenberg design for a DAC Type 4 on 21 September 2021.

4.2 Outlook Phase II

In Phase II, the demonstrator train will be successively extended to 24 wagons and the selected coupling design tested in regular RFT operations. The aim is to test the DAC prototype in operational situations and processes and gain experience about its behaviour in real operations. In 2021, the demonstrator train will initially run on selected German routes. From the beginning of 2022, it will also run in Switzerland and Austria. In addition, DAC4EU approached other EU countries in order to perform test-drives on their respective tracks. The aims are to gather further knowledge about the DAC Type 4 with a focus on operational handling and to document technical information gathered during Phase I in greater detail. This phase will also be used to present the advantages of the DAC and show the demonstrator train to external stakeholders. Operational testing is scheduled to be completed in December 2022.