Realization and testing of the Extended Market Wagon

Reaching TRL6 with an innovative freight wagon in Fr8Rail 4, a Europe's Rail Project

Lightweight, freight, Europe's Rail, Fr8Rail

The Extended Market Wagon (EMW) (see article start image) is an advanced lightweight freight wagon that was developed as part of the Fr8Rail 4 project in Europe's Rail in the Shift2Rail IP-5 programme. In a previous article, the lightweight design developed for the EMW by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) within the Competitive Freight Wagon (CFW) consortium was described [1]. In the following article, the subsequent manufacture of the final wagon design will be described, as well as the display of the wagon at the InnoTrans 2022 in Berlin and its testing under real world conditions in Velim in Czechia.

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The EMW, as previously described, consists of semi-permanently coupled two-axle wagon pairs that can each transport two swap bodies [3]. In accordance with the requirements of the Fr8Rail project, the EMW was developed with a loading height of less than 1000 mm in order to be able to transport 2.9 m tall high-cube swap bodies even on routes with smaller loading gauges [3]. The choice of loading height has a significant influence on the design of the concept, as the wheelset dimensions and also the coupling height are affected by this parameter.

The Institute of Vehicle Concepts at the DLR was responsible for the design, simulation, implementation, and assembly of the structural components of full-scale demonstrator [4]. The wagon and bogies frames were manufactured as welded assemblies using S355 J2-grade steel (Figure 1, Figure 2). For the assembly of the EMW, the various parts of all partners involved were assembled and installed over several weeks in summer 2022. This included wheelsets, electronics, aerodynamic fairings, couplers, automatic locking container pins and compact EP-Brakes. During assembly, various functions such as the remote access and localisation telematics as well as the hardware functionality of the type 5 Digital Automatic Coupler (DAC) and the air suspension were successfully tested. The type 5 DAC represents the highest level of automation for DACs, with coupling and decoupling able to be fully remote-controlled [5]. The completed EMW with all tested components was successfully presented at the InnoTrans in September 2022 (Figure 3), where many of the above functions were demonstrated to the interested public.

Following the InnoTrans and in the period leading from 2022 to 2023, a series of experiments were planned which were designed to test and verify various simulated results and the overall running safety and stability of the wagon under real-world conditions. A testing site and an experienced testing provider were selected, the final choice being VÚKV at the test facility operated by VUZ (Výzkumný Ústav Železniční, a. s.).

The tests planned were as follows:

1. Test for safety against derailment (quasi-static torsion test in accordance with EN 14363 Method 2) [6]

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   - Wagons in five loading conditions, empty to 24 tonnes loaded
   - Measurement of wheel forces on a test stand
   - Measurement of the wheel-rail forces in a flat 150m curve
2. Driving test in an instrumented curve at low speed (R = approx. 150 m)
   - unloaded and fully loaded with 24 tonnes
   - Forces measured using instrumented track in 3 measuring positions according to EN 14363 [6]
3. Driving test according to EN 15839 [7] in an S-curve with small radius (150 m)
   - Fully loaded with 24 tonnes
4. Driving test on a straight track and in curves with large radii (1400 m)
   - unloaded and fully loaded with 24 tonnes
   - Checking driving stability/safety up to speeds of 140 km/h

The basic wheel-rail interaction forces (Y, Q) were measured in an instrumented track section as described above. The use of conventional measurement wheelsets was not practicable in view of the EMW's non-standardized wheelsets and its use of wheel brake discs. As sufficient information could be collected with the help of instrumented tracks and various displacement and acceleration sensors, the production of measuring wheelsets was considered an avoidable risk.

A wide variety of sensors were to be used to measure the relevant variables, such as draw-wire sensors, accelerometers and plunger-type displacement transducers. The following variables were measured by the VÚKV during the trials:

1. Wheelset yaw
2. Vertical primary suspension
3. Lateral primary suspension
4. Vehicle roll
5. Potential pitching movements of the bogie frame
6. Accelerations
7. Secondary suspension lateral travel
8. Secondary suspension vertical travel

The tests were to include runs with both active and deactivated air suspension, but problems with the air suspension's sensor system became apparent after the period in which the wagon was parked outdoors over the winter of 2022/2023. Due to supply difficulties with spare parts, it was decided to carry out the tests with the air suspension switched off. As this condition (driving on emergency springs/empty air springs) represents the most unfavourable configuration with the lowest possible torsional flexibility and is usually the most critical case, the tests are relevant for an evaluation of safe driving behaviour under these conditions.

The tests began in May 2023 with the derailment safety test. This two-part test consisted of a torsion test to determine the wheel-rail forces with a mobile test stand (Figure 4) as well as on a section of instrumented track. With the test stand, a testing unit is mounted under each wheel to alternately lift diagonally opposed wheels. Displacing wheels at opposite ends of the wagon in opposite directions forces the EMW to twist about its x-axis, thus simulating driving in strongly twisted track, for example representing the transition into or out of a superelevated curve. The measurements were carried out with five dif-


Figure 1 Wagon frame of the EMW during fabrication


Figure 2 Welded EMW wagon frame being prepared for painting

Figure 3 The EMW on display at the InnoTrans 2022

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ferent loading scenarios, from completely empty to fully loaded. The loading was realized using steel frames with corner castings corresponding to the dimensions of 20-foot containers. Concrete slabs were placed in these frames until the target mass of 12 t was reached for each frame (Figure 5). After each increase in mass, the measurement was repeated to determine the Q/Q relation.

Despite the stiff emergency springs, the frame and emergency springs exhibited sufficient compliance without the wheels being unloaded, even when the empty wagon was twisted to the greatest extent. These results were later confirmed when the wheel-rail forces were measured in the instrumented track. The tests showed that the results of the torsion test in the unloaded wagon with deflated air springs corresponded very well with the results of the MBS. In the MBS, the minimum wheel contact force Qjk,min was 11.8 kN, whereas in the torsion test, Qjk,min was between 10.2 and 17.1 kN.

The positive results of the previous tests indicated that the wagon was safe for higher speed testing on the large test ring. The driving tests were initially carried out in an unloaded state (Figure 6). The tests were started at a speed of 30 km/h and the speed was gradually increased by 10 km/h steps to the target speed of 140 km/h. The unloaded tests were successful; the car remained stable and ran smoothly despite the air suspension being switched off. This was consistent with the simulation results from the multi-body simulation (MBS), which had shown stability up to 200 km/h under most loading conditions.

After the positive driving test results with the unloaded EMW, the wagon was loaded with 24 tonnes and testing continued. These tests also began at a speed of 30 km/h, with the aim of gradually increasing this up to 140 km/h. During the test, however, the rear wheelset began to develop unusual drag from approx. 30 km/h in a curve with approx. 140 mm superelevation. For safety reasons, and in order to inspect the affected wheelset, the test was halted. An in-depth investigation of the cause was not possible with the resources and time available on site, however initial indications point to unexpected friction in the labyrinth seal. As the issue could not be solved at the time, it was decided to delay fur-

Figure 4 EMW undergoing torsion testing on a mobile test stand

Figure 5 Torsion testing of the EMW loaded with two 20-foot steel frames and concrete slabs to 140 km/h

Figure 6 The unloaded EMW being prepared for testing at up to 140 km/h

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ther test drives until further analyses could be carried out. Nevertheless, it was observed that the EMW exhibited stable and safe driving behaviour during the incident.

With the conclusion of the EMW's first extensive testing campaign, the vehicle has attained the level of maturity and technology readiness needed to prove its viability in the real world. The essential functions of the wagon have been successfully demonstrated, and evidence suggests that simple repairs and minor modifications of tolerances are all that will be necessary for the resolution of the problems described above. The tests themselves represent the culmination of the extensive work that went into preparing for them, but also the considerable effort by those involved to shepherd the wagon from its concept phase through the design, simulation, and manufacturing processes, all the way to the testing grounds in Velim in Czechia. ■

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Eingangsabbildung/Article start image: Dimensioned conceptual view of the EMW with two high-cube swap-bodies, left the DLR's FR8-LAB aerodynamic measurement container [2]

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