

efWING

– New-Generation Railway Bogie



Part of the frame of this railway car bogie is made of CFRP (Carbon Fiber Reinforced Plastics). In addition, the CFRP frame is designed to function as a coil spring suspension as well to integrate two functions into one. efWING is the world's first railway car bogie that uses carbon fiber, i.e., an advanced material that has been used for aircraft. By taking advantage of the material's properties, a substantial weight reduction has been achieved so as to enable the cost of operating energy to be reduced.

Introduction

Recently, in consideration of global environmental issues, there has been a growing trend to save energy. Under these circumstances, railway cars are also expected to save energy. The most effective way to save energy, in other words, reduce running costs and CO₂ emissions, is to reduce the weight of railway cars.

1 Background

A railway car is divided into two parts, namely, a carbody and a pair of bogies. For the carbody shell, which carries passengers and cargo, substantial weight reductions have been achieved by using stainless steel, aluminum alloys, and other materials. On the other hand, for the bogie, which takes on the role of running, optimization analysis techniques based on numerical simulations, including the finite element method, have been leveraged to implement weight reduction measures by means, for example, of reducing the plate thickness and providing the weight reduction holes, to date. In recent years, however, there has been a tendency for bogies to be equipped additionally with a variety of devices and components, including damping equipment and sensing devices, to improve railway car's running performance as well as condition monitor for railway car. Such devices and components contribute to weight increases and no further weight reductions can be easily achieved by existing measures. For this reason, there has been a need to fundamentally change the conventional design concept.

Meanwhile, applications of composite materials are

steadily expanding not only in the railway car industry but also in the aviation and motor car industries from the viewpoint of weight reduction. For example, CFRP (Carbon Fiber Reinforced Plastics) has begun to be used proactively for the main structure of Boeing 787 and other civil aviation aircraft as well. In addition, the use of CFRP has been expanded also to railway cars (more specifically, bullet trains' front ends and covers). These trends have provided an impetus to its use for bogies as well.

To date, railway car bogies have been recognized as running gear, i.e., a critical component, and therefore have been designed with an emphasis on operation results for several decades. Based on the aforementioned backdrop, however, we had considered fundamental changes in the bogie structure and review of applicable materials, and consequently accelerated the development of efWING, a weight-saving bogie with improved running safety.

2 Course of events that led to development

(1) Development of a CFRP leaf spring

Since 2011, we have been advancing the development of a CFRP leaf spring and have developed its design based on the load conditions for conventional lines in Japan as a three-point bending spring element, which is suspended at its both ends and subjected to a vertical load at its center. In this connection, a radius arm type for primary suspension (which has been service-proven) has been adopted to suspend the axle box in longitudinal and lateral directions and is available for the purpose of eliminating the need to incorporate a major developed element in this part

to realize configuration that would be easily accepted in the commercialization phase.

First, a static load test was conducted to verify the strength and rigidity of the spring alone. As a result, it was proven that the spring had the predetermined spring constant and that it had static strength with an adequate safety factor with respect to the full load condition, i.e., the maximum load applied during actual service. In addition, a railway car materials combustion test was conducted to check for flame retardancy, which the aforementioned CFRP leaf spring must have as a material applied for railway cars. As a result, it was revealed that the CFRP leaf spring was incombustible.

(2) Prototyping

A narrow gauge bolsterless bogie for use on conventional lines equipped with the aforementioned springs was prototyped. An assessment was conducted on the bogie using a rotary tester owned by Kawasaki with regard to the bogie's essential running performance. As a result, it was confirmed that the bogie was able to run without hunting even though the push/pull load was applied to the bogie up to 200 km/h, which sufficiently exceeds the running speed of commuter train.

In May 2012, the second prototype bogie, which had been fabricated in view of an actual running test, was completed. As the second prototype, a standard gauge bogie with bolster was adopted in view of an actual running test. Following the completion, a fatigue test was conducted on the leaf spring in parallel with a static load test and a rotation test for the bogie. As a result, it was confirmed that the second prototype had such performance, strength and durability that it was available

for a test run.

Moreover, a bogie equalization test was conducted prior to the actual running test. This bogie equalization test was based on the unforgiving U.S. specification/standard, which requires that if any one of the wheels in one bogie becomes depressed or rises due to track irregularities, the vertical load between the wheel and the rail (wheel load) should not decrease. Figure 1 shows the results of this test. Conventional bogies have been designed allowing for little margin with respect to the limit values for conventional lines, as shown in Fig. 1. With regard to efWING, on the other hand, there was substantial margin with the amount of decrease of wheel load not more than 50%, compared with conventional bogies. In other words, it can be interpreted that the ability of efWING's wheels to track rails was two times that of conventional bogies. Consequently, it could be confirmed that efWING had excellent performance in terms of running safety. This is because the CFRP leaf springs balanced the wheel load on the front wheels with the wheel load on the rear wheels like a seesaw with the spring's central part acting as a fulcrum. It can be said that this high bogie equalization performance is a major feature of efWING.

(3) Running test

In June 2012, a running test was conducted at Transportation Technology Center, Inc. (TTCI) in Colorado in the United States (a subsidiary of the Association of American Railroads). This test was conducted using a four-car train: the first car was a traction locomotive; the second car was a gauging car loaded with measuring instruments; the third car was a passenger car with conventional bogies to compare with efWING; the fourth car was a passenger

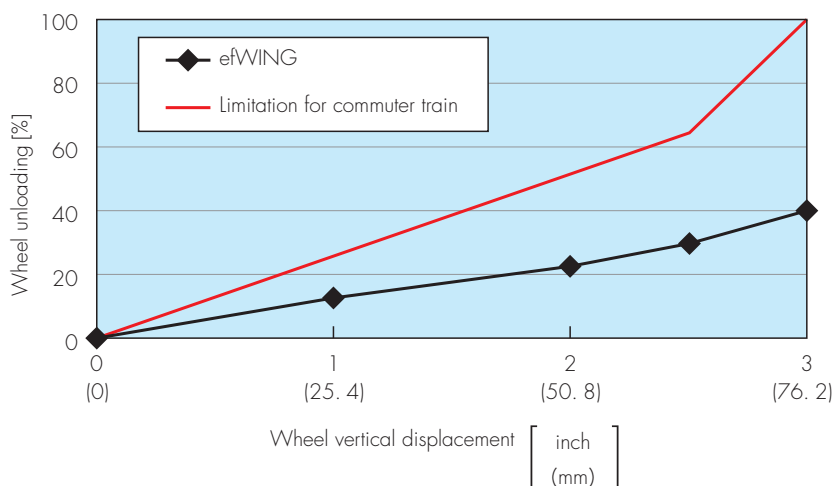


Fig. 1 Wheel unloading requirement



Fig. 2 Running test car

car with efWING, instead of conventional bogies (Fig. 2).

The running test was conducted for a total of 20 days, achieving a car mileage of 4,469 km. Of the multiple loop tracks located in TTCL's site, the longest high-speed track has a total circumference of 21.7 km. With the maximum speed set at 160 km/h. i.e., the critical speed of hunting for the locomotive, running was repeated. In addition, test data on sections with a 145-meter radius, high degree curve and "sections with a figure 8" or other high degree switches were also accumulated. Moreover, all types of sections with extraordinary track irregularities, i.e., pitch and bounce sections, where vertical irregularities of the left and right rails are in phase with each other, twist and roll sections, where such irregularities are in reverse phase with each other, and yaw and sway sections, where lateral irregularities of both rails are in phase with each other, were run to ascertain the dynamic properties, including strain, acceleration and wheel load histories.

efWING met the requirements regarding the running safety of railway cars, as stipulated by FTA (Federal Transit Administration), throughout the speed range of 48–160 km/h. Consequently, it was proven to be able to run safely.

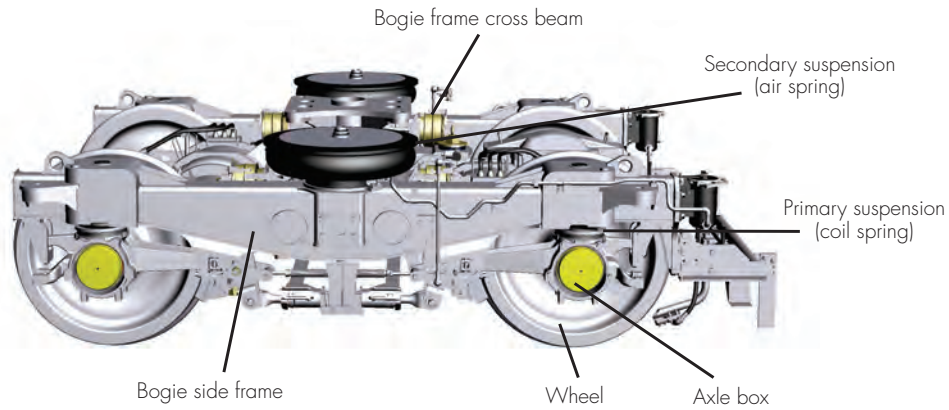
3 Basic structure

Generally, a railway car bogie consists of main structure components and equipment necessary for running. The main structure components include four axle boxes, in which journal bearings are housed, an axle box suspension structures and a bogie frame structure. The equipment

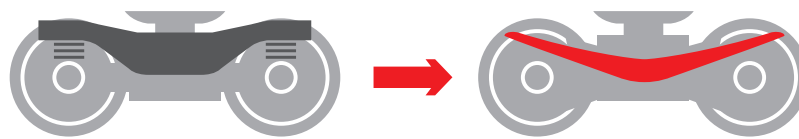
necessary for running includes motors, gears, brakes and suspensions.

efWING is a bogie that was devised as a result of fundamentally reviewing conventional bogies' functions without being obsessed with the conventional bogie structure. The concept of efWING, focusing on the carbody load transmission path in conventional bogies as illustrated in Fig. 3 (i.e., carbody → secondary suspension (air springs) → bogie frame cross beams (transom) → bogie frame sidebars (side frames) → primary suspension (coil springs or the like) → axle boxes, axles and wheels → rails), is to replace the bogie frame sidebars and primary suspension, out of the components constituting the aforementioned path, with a pair of CFRP leaf springs to achieve structural simplification and weight reductions.

Due to such replacement, the frame structure could be entirely changed to eliminate the need for sidebars. In the context of comparing the bogie that underwent a TTCL test with a conventional bogie for use in North America, the bogie mentioned first has achieved approximately 40% of reduction in bogie frame weight with respect to the conventional bogie, which is equivalent to a weight reduction of 900 kg per car. In addition, efWING has achieved simple assembly structure as well. The leaf springs are simply placed on the axle boxes without being fastened to the axle boxes or the bogie frame cross beams with bolts, pins or the like, and the bogie frame cross beams are also mounted simply through the fulcrum at the center of the leaf springs.



(a) Commuter bogie structure



Side frame and coil springs

CFRP leaf spring

(b) New-generation bogie structure

Fig. 3 Design concept

4 Design pursuit

Since the beginning of the development of efWING, we have pursued design that allows the presence of the bogie to be demonstrated keeping it in mind that unprecedented coloring should be adopted to make the bogie impressive. To date, only carbodies have drawn attention. However, the bow-like spring taking advantage of CFRP's performance led the way to the creation of a bogie that has innovative appearance as well. We applied for the Good Design Award, which we had long hoped to receive, and won a gold award in 2013. On that occasion, we received comments from the reviewers, including the following—"I would like to highly appreciate the creation of a high-performance bogie with functional beauty from new material technologies and structural development of which Japan is proud." This is an outstanding achievement in that we received an award related to bogie design for the first time.

5 Expansion of domestic applications

Kumamoto Electric Railway Co., Ltd. had replaced two conventional bogies used for its Series 6000 EMU with efWING bogies and brought the EMU into commercial

operation on March 14, 2014 (Fig. 4).

Moreover, in March 2015, Shikoku Railway Company conducted a test on efWING's applicability to car commercially operated in Japan. The test results are shown below.



Fig. 4 Series 6000 EMU operated by Kumamoto Electric Railway Co., Ltd.

(1) Tested cars

A running test was conducted using a 121 Series DC suburban EMU equipped with test bogies as shown in Fig. 5 (a).

With the Tadotsu–Takahama section (66.7 km) on the Yosan Line set as the test section, a running test was conducted at speeds of up to 100 km/h for five days.

(2) Running safety

Running safety was assessed using three evaluation items: derailment coefficient, decrease ratio of wheel load and lateral force. It was confirmed that the eWING test bogie met the guidelines for all items. In addition, running safety was assessed also by maximum carbody floor vibration acceleration. Assessment guidelines were set to



(a) Bogie for Series 121 operated by Shikoku Railway Company



(b) Bogie for Series 817 operated by Kyushu Railway Company



(c) Bogie for Series 7000 operated by Nishi-Nippon Railroad Co., Ltd.



(d) Bogie for Series 7200 operated by Shikoku Railway Company

Fig. 5 Bogies used for running tests conducted by railway companies

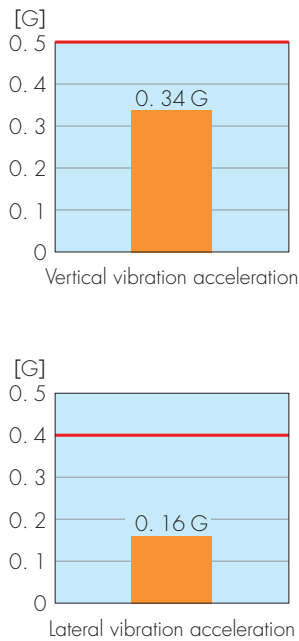


Fig. 6 Comparison of remarkably high values of carbody floor vibration acceleration (efWING test bogie)

0.5 G and 0.4 G for vertical vibration acceleration and lateral vibration acceleration, respectively. It can be understood from Fig. 6 that both vertical and lateral vibration accelerations met the respective applicable guidelines.

6 Expansion of applicability to various cars

Following the commencement of the aforementioned commercial operation, Kumamoto Electric Railway Co., Ltd. brought into commercial operation two Series 01 cars that have efWING bogies on March 16, 2015 and two more Series 01 cars that have efWING bogies on March 1, 2016.

Following the aforementioned running test conducted by Shikoku Railway Company, other running tests were conducted by Kyushu Railway Company and Nishi-Nippon Railroad Co., Ltd. in April 2015 and October 2015, respectively. The efWING bogies as shown in Figs. 5(b) and 5(c), both of which had replaced conventional bogies, were used for the earlier and later running tests, respectively.

Moreover, Shikoku Railway Company had planned to renew the major equipment for 121 Series DC suburban EMUs and has brought into commercial operation 7200 Series with efWING as shown in Fig. 5(d) in June 2016.



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Conclusion

Running safety and ride quality of efWING have already been verified and commercial operation is being started. In the future, we will make further technological improvements and endeavor to develop efWING into an innovative technology and disseminate it to railway operators in Japan as well as in other countries around the world.

We hereby express deep gratitude to everyone who has continued cooperating with us until efWING became available for commercial operation.