Development of Bogie for User Friendly, Extra Low Floor, Light Rail Vehicle (LRV) Using Independent Wheel System and Next Generation LRV

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The next generation, extra low floor, light rail vehicle (LRV) is increasingly drawing attention as a user friendly and comfortable urban traffic system. Mitsubishi Heavy Industries, Ltd. (MHI) has developed a bogie for the LRV by building the first domestic independent wheel system, and an extra low floor LRV, called the Green Mover Max, equipped with this bogie is now operating without trouble for Hiroshima Electric Railway Co., Ltd. In the course of the development of the bogie, both the electric powered bogie and the motor-less bogie were the subject of exhaustive design discussions and a thorough technical verification was carried out so that differentiation from the vehicles of foreign manufacturers and customer needs were attained. As a result, a vehicle with a high percentage of completion was able to be realized. Further, we have already started work on the development of the next generation LRV which is equipped with secondary batteries and does not use overhead lines and on the development of a vehicle suitable for urban service operation, aiming to further expand the market for the 100% extra low floor LRV.

1. Introduction

The first domestically-made independent wheel type 100% extra low floor LRV started service operation on the streets of Hiroshima on March 30, 2005. The vehicle, called the Green Mover Max, became a reality five years after it was conceived, after overcoming many problems over that time. This paper describes the development of its key component, the independent wheel type bogie and also an outline of the vehicle. It also describes the development of the next generation LRV which is expected to show increasing growth in future.

2. Concept of development

The Green Mover Max was developed as a joint project of three companies, Mitsubishi Heavy Industries, Ltd. (MHI), Kinki Sharyo Co., Ltd., and Toyo Denki Seizo K.K. with Hiroshima Electric Railway Co., Ltd. acting as an advisor in the field of operation service. The four companies mustered their efforts in the development and manufacture of the LRV (light rail vehicle) in harmony with the Japanese landscape and Japanese society using Japanese technology.

Three points were listed in the development concept: (1) ultimate, (2) user friendly, and (3) urban. The initial letters of these points were used to name the project the U3 Project. In the U3 project, MHI took the bogie, brakes and inner and outer riggings, Kinki Sharyo focused on design, car body, articulation and the driver's cabin, and Toyo Denki Seizo took responsibility for electrical parts and control and drive units.

The new generation urban traffic system LRT (light rail transit) is drawing attention as a symbolic city transport system that is comfortable and friendly not only to the environment but also to people. In particular, the high performance, stylish, barrier-free, and extra low floor tram, well beyond existing tram concepts, has already been introduced in Europe and North America, and its effectiveness has been highly evaluated.

However, European manufacturers are ahead of Japanese ones in terms of the technology for independent wheel bogies, so that the 100% extra low floor LRV introduced to Japan was limited to vehicles manufactured by foreign manufacturers or partially manufactured by domestic makers by adopting foreign technology.

This gave rise to operability and maintenance problems, and the development of a domestic vehicle for use in Japan was an immediate need and was long awaited. The first 100% extra low floor LRV developed with Japanese technology is 30 m long and has a 5 car, 3 bogie configuration. MHI was involved in the project for the development, design, manufacturing and verification of the bogies based on the achievement of "Technical Research Institute for Extra-Low-Floor Bogie" established by the Land, Infrastructure, and Transportation Ministry, and has realized a wide range of traveling performance such as barrier-free charter, low noise, low vibration, low speed, and high speed.

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3. Development of technology for independent wheel bogie

The key to the development of the 100% extra low floor LRV was the bogie with an independent wheel system. Normally, the left and right wheels are connected with a shaft, which determines the floor height. Therefore, an independent wheel system without shafts was adopted for our bogie. The electric-powered bogie (**Fig. 1**) has its motor and drive unit installed outside of the wheels. The adoption of the new bogie system allowed a floor height of 330 mm (passage section 360 mm), enabling step-less boarding into the car. In addition, the bogie structure was made compact to allow an 880 mm wide aisle (located immediately above the bogie) of 50 mm wider than the LRV manufactured by foreign manufacturers. Moreover, the motor-less bogie (**Fig. 2**) with no motor installed was specially designed to drastically increase the width of the aisle to 1,120 mm thus contributing to the smooth movement of passengers boarding and alighting while ensuring a wider and unobstructed view from the passenger compartment.

Elastic wheels were adopted to reduce noise and vibration. As for brakes, three types (electric, hydraulic, and rail) are used to allow speed changes with fewer shocks to bring the car to a safe stop under all conditions.

As the bogie is one of the most important parts of the vehicle, the bogie frame, its most crucial part, was subject to strength testing on a step-by-step basis including FEM analysis, static load testing (**Figs. 3** and **4**), fatigue testing, and actual load stress measurement, in that order. In particular, the static load testing and the fatigue testing were conducted by using the prototype bogie frame, whose results were reflected in the mass production design. In the static load testing, from stress measurement at about 280 points on the motorized bogie frame and about 250 points on the motor-less bogie, no problem was identified regarding strength. In the fatigue testing, each bogie frame was repeatedly loaded continuously for about one month and 3 million times in total, and it was confirmed from magnetic particle testing that there were no cracks or permanent deformations. Following the fatigue tests, the bogie frame was cut and examined, and no problem was identified.

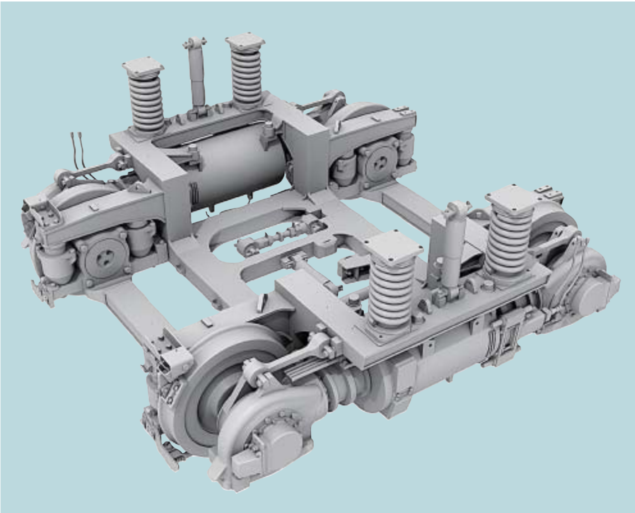


Fig. 1 View of motorized bogie

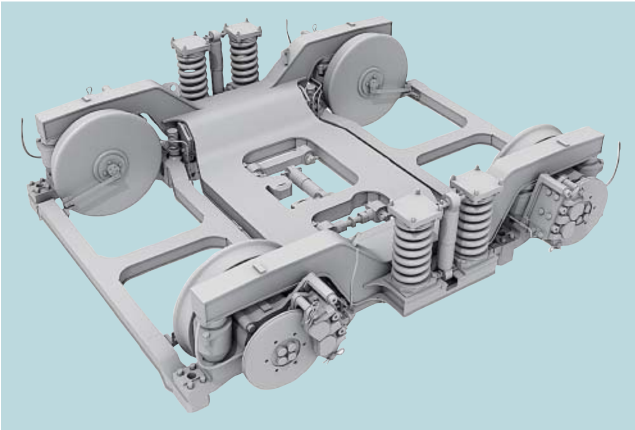


Fig. 2 View of motor-less bogie

Fig. 3 Static load test of motorized bogie frame

Fig. 4 Static load test of motor-less bogie frame

When testing the vehicle, MHI built a special 900 m long test rail track at the Plant and Transportation System Engineering & Construction Center in the company's Wada-Oki Plant. A thorough verification of the technology was carried out at this test track to realize a vehicle with outstanding performance (**Fig. 5**).

We verified the acceleration and deceleration performance and safe running performance on the test rail track by measuring the car body behavior and the strength of the bogie and car body parts. We also measured the ride quality and the noise inside and outside the car to verify the ride comfort. The independent wheel bogie behavior was observed by a camera to verify running stability and measure the wheel load and lateral force to verify that it would not derail, and confirmed there were no problems. We established a method of measuring the wheel load and lateral load and have applied for a patent.

4. General specifications for vehicle

Table 1 shows the general specifications of the Green Mover Max. The vehicle main body is equipped with a Train Information System (TIS), and the monitor is fitted to the driver's control platform. Thus the control platform was made compact, with centralized switches, due to the use of a monitor. Driving and maintenance support is possible by using maintenance and problem indicators to reduce the workload of the driver who is responsible for both operating the vehicle and processing passengers.

The vehicle control system employs an individual motor control system using a VVVF inverter unit with high energy performance, where the difference in rotational speed of the left and right wheels due to the 100 kW motor installed outside the driving bogie (4 units per 1 train) and the unbalanced torque due to the wheel radius are absorbed to ensure outstanding running performance.

Fig. 5 Traveling test on test rail track

The car body is made of steel for its safety, stiffness and maintainability which are required for vehicles traveling on the road. Thanks to the thorough measures taken to reduce weight, a car with a strong and light body has been realized. In the 5 car, 3 bogie configuration, the central cars are floating, and the articulations connecting each car body ensure high reliability, while being light in weight, compact in size and needing little maintenance.

The vehicle was designed to have a soft, roundish, front end to provide a fresh feeling and friendly flavor to the passengers as the new domestic extra-low-floor vehicle.

The interior design was based on the concept of a comfortable space, and maple motifs, the symbol of Hiroshima, were used on the inside and outside of the car body to give the local tone required of a tram car.

5. Development of next generation LRV

An outline of the Green Mover Max and the development of the bogie have been described above. In March 2007 the Green Mover Max with a train formation of seven vehicles was introduced in the city of Hiroshima and the tram car became widely recognized and loved by its citizens.

We believe that the domestic manufacture of the 100% extra low floor LRV has triggered the diffusion of the LRV to various cities in Japan and we have already started the development of the next generation LRV, aiming to further expand sales of the 100% extra low floor LRV.

Table 1 General specifications of vehicle

Configuration	5 car, 3 bogie, extra-low-floor vehicle
Number of passengers	149 (56 seated)
Weight (t)	33.9
Size (mm)	*L* 30 000 × *W* 2 450 × *H* 3 450
Floor level, low floor rate (mm)	360 (doors 330), extra-low-floor rate 100%
Electric mode (mm)	DC 600
Track gauge (mm)	1 435
Maximum speed (km/h)	60
Acceleration (km/h/s)	3.5
Normal deceleration (km/h/s) Emergency deceleration (km/h/s)	4.8 6.0
Main control unit	2 level IGBT-VVVF inverter, Regenerative and generation blending brake system
Brake unit	Mechanical (hydraulic) brake system, regenerative and generation brake, safety brake (track brake), deadman's handle
Main motor	Three phase squirrel cage induction motor 100kW × 4 units
Bogie	Shaftless, independent right and left wheel rotation type bogie

Fig. 6 Test vehicle not using overhead line

Fig. 7 Car interior

The first development is a hybrid LRV which does not use overhead lines and employs lithium ion secondary batteries. Due to its merits including a better cityscape along the route by eliminating the overhead lines and an increase in energy recovery rate attained by preventing energy regeneration loss, it is already being studied by various research institutes and vehicle manufacturers. In Europe, the commercial operation of a tram equipped with secondary batteries and not using overhead lines has already started in limited sections.

MHI has conducted various running tests on its in-house test tracks utilizing used vehicles supplied by Hiroshima Electric Railway (**Fig. 6**) to study systems, running performance, and battery life.

The second development is a system with a smaller number of cars per train than the Green Mover Max. While the Green Mover Max is 30 m long and has a 5 car, 3 bogie configuration, a new system having 18 m long with a 3 car, 2 bogie configuration is now developed, aiming at a vehicle suitable for urban service operation.

Thirdly, aggressive efforts are under way for technological development and next generation concept design focusing on the design of the inside and outside vehicles. As trams have a role as a symbol of a city, stylish design is desired. MHI is making the most of our company designers in discussing designs suitable for the next generation LRV.

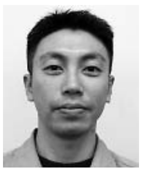
Figure 7 is an illustration of the new concept vehicle for the next generation LRV.

6. Conclusion

The development of the bogie for the first domestically made, 100% extra low floor LRV and the development of the next generation LRV have been described above. The development involved a number of new elements such as the independent wheel type bogie not used in conventional vehicles, therefore technical verification in various fields was required. As a result of these efforts, a domestically manufactured model was realized and MHI has been able to contribute to the development of the LRV market in Japan. MHI will continuously upgrade our technology and promote the next generation LRV, while hoping for the increased introduction of domestically manufactured low floor vehicles in various areas.

Finally, we would like to extend our gratitude to Hiroshima Electric Railway Co., Ltd., the Technical Research Institute for Low Floor LRV Bogie, Kinki Sharyo Co., Ltd., and Toyo Denki Seizo K.K. for their valuable cooperation and guidance in the development of the first domestically made, low floor LRV.



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