Adoption of Articulated Structure in AC Train

Ryohei Shimamune*, Takahiro Kikuchi*, Hiroshi Nomoto* and Mitsuyuki Osawa*

The AC Train that is destined to become the next-generation suburban commuter train is the first JR East suburban commuter train to adopt the articulated structure. In the AC Train, we developed two types of articulated systems to make a comparative study of running performances and articulated structure. We have started running tests of AC Train in February, 2002 and verified that there was no problem on the running safety. As the next step, we plan to achieve further refinement of the articulation method by the improvement of articulated structure.

● Keyword : AC Train, Articulated structure, Articulated bogie, Articulated car body, Running safety

1 Introduction

JR East has developed the AC Train test car (Series E993) that is planned to become the next-generation suburban commuter train. This car is the first JR East suburban commuter train to adopt the articulated structure. The articulated system is designed in such a way that a bogie is arranged on the connecting portion of the cars to support the cars at the front and back, unlike the common bogie car where the car body is supported by two bogies. The major examples are found in the limited express trains (Romance Car) of the Odakyu Electric Railway Co., Ltd., Enoshima Electric Railways Co., Ltd. and Hiroshima Electric Railway Co., Ltd. JR East adopted it in the Shinkansen high-speed test car (Series 953:STAR21) developed in 1993.

To make a comparative study of the running performances and articulated structure in the AC Train, we have developed two types of articulated structures; two-point air spring support structure and four-point air spring support structure. This paper reports the overview of the articulated trainset composition, the structure of the articulated bogie and car body, and results of the running test.

2 Adoption of articulated train composition

The common reasons for the adoption of an articulated structure can be enumerated as follows: (1) The buffer device of the coupler can be eliminated, with the result that riding comfort is improved due to reduced back-and-forth vibration. (2) The on-train environment is improved since the passenger compartment can be separated from the bogie. (3) In an exclusively two-storied car, the floor space is increased because the length of the second layer can be increased.[1][2]

In addition to the reasons enumerated above, the articulated structure in the AC Train was intended to reduce the cost and weight of the car through reduction in the number of devices per trainset, and to increase the passenger space by increasing the width of the car body.

In the case of the conventional bogie car, the required number of bogies is obtained from the number of car bodies multiplied by two. In the articulated structure, however, the bogie is located at the connecting portion of cars. So the number of bogies for each trainset can be reduced to the number of car bodies plus one. For example, the train generally used in the metropolitan area at present is a 200-

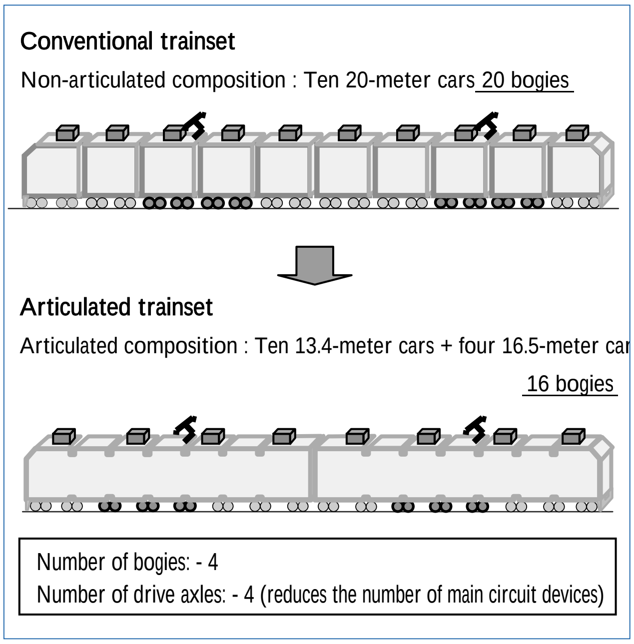

Fig. 1 Reduced number of bogies in articulated structure

*Advanced Railway System Development Center, Research and Development Center of JR East Group

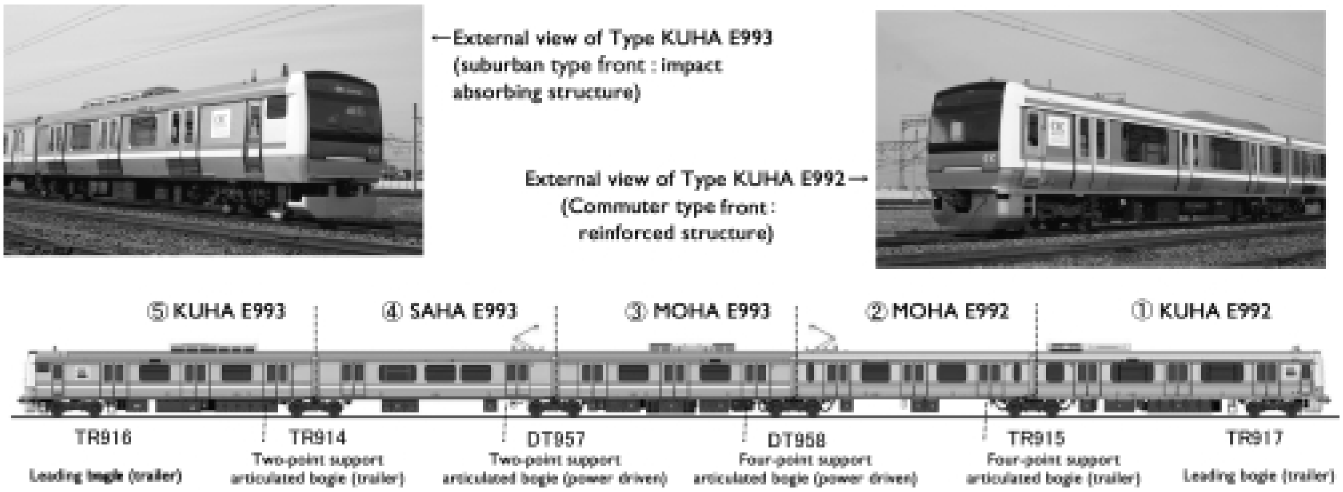

Fig. 2 AC Train Composition

meter long 10-car train, each car measuring 20 meters in length. When the articulated structure is used for this trainset, the same length can be obtained by linking fourteen 13-meter cars. This allows the number of the bogies to be reduced by four. (See Fig. 1).

Further, the drive force for acceleration of the train depends on the adhesion of the wheel rolling on the rail that transmits power. This adhesion is given by Equation (1).

$$F = \mu \cdot W \tag{1}$$

Here μ denotes adhesion coefficient and W axle weight. This Equation shows that adhesion is basically dominated by the value for the wheel load as well as adhesion coefficient affected by the conditions of the wheel and rail surfaces. Since both car body weight and wheel load are reduced in cars of recent times, it is getting difficult to increase the driving force. On the other hand, the number of the bogies per trainset is reduced in the articulated structure, so wheel load per axle is greater than that of the conventional car, and it is possible to increase adhesion. This permits the numbers of the driving axles and driving cars (the number of main circuit devices) to be decreased.

Further, as will be discussed later, the passenger space can be made wider than that of the conventional bogie car by expansion of the car width and use of the corridor connection of the articulated structure.

To make a comparative study of the running performances and articulated structure, the articulation method of the AC Train adopts two types of articulated structures; two-point air spring support structure and four-point air spring support structure. Fig. 2 shows the AC Train composition. The four-point air spring support structure is used between cars No. 1 and 2, and between cars No. 2 and 3, and the two-point air spring support structure between cars No. 3 and 4, and between cars No. 4 and 5. Of six bogies, two are driving bogies, and the MT ratio is 1 to 2.

In the articulated structure, the intermediate articulated bogie is located at the articulation of the car. The train set is not normally separated, but it is necessary to mark divisions in order to define the sequence of separating the cars at the factory. So each car body and its forward bogie form one set, and only the even-numbered control car (KUHA E992) is provided with two bogies. As will be discussed later, both types of articulated structures are designed in such a way that the car on the side of the odd-numbered leading car (KUHA E993) is mounted on top. The car and bogie are combined in a matched relationship.

3 Structure of articulated bogie

3.1 Overview of the bogie

Articulated bogies are used as the middle bogies, excluding the leading bogies on both ends. Two types of these articulated bogies are provided; a two-point air spring support type articulated bogie (hereinafter abbreviated as "two-point support articulated bogie"), and a four-point air spring support type articulated bogie (hereinafter abbreviated as "four-point support articulated bogie").

3.2 Two-point support articulated bogie

(1) Overview of the structure

The articulated bogie with two bolster springs on the right and left is often used on the cars of articulated structure in Japan. Generally, in this bolster spring, the car body is supported by the side bearer according to the indirect mount method. The two-point support articulated bogie adopted in the AC Train is designed in a bolster-less configuration characterized in that maintenance is improved by abolition of the sliding portion and weight is reduced. The bolster beam on the car body side for supporting the air spring is provided on the articulated portion in such a way that it overhangs from one of the cars. This bolster beam is located lower than the bottom surface of the car body in order to avoid interference whereby the car comes into contact with the counterpart car when rounding a tight curve. Since the air spring must be installed further below this bolster beam, bogie frame side beams are bent sharply so that the height over the air spring is reduced 830 mm. (Fig. 3)

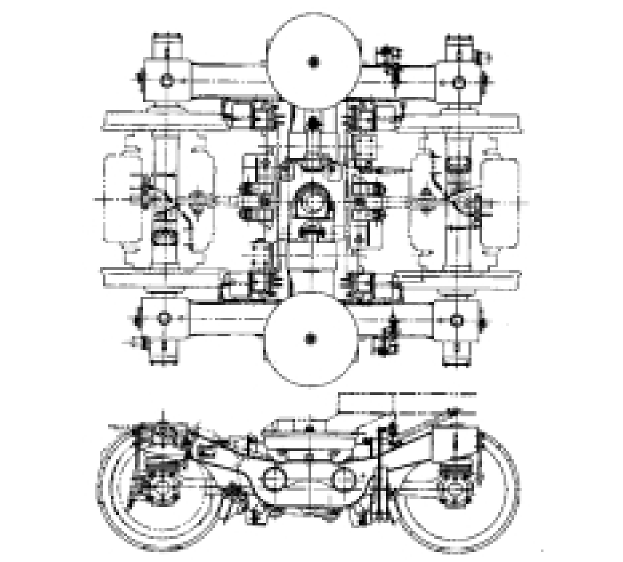

Fig. 3 Two-point support articulated bogie

(2) Strengthening the bogie and brake equipment by articulated structure

Since the AC Train has a smaller number of bogies per trainset, there is an increase in the load and braking force to be borne by each car. To solve this problem, the wheel, axle, axle spring and bogie frame are designed to meet the maximum axle weight of 16 tons. The foundation brake is designed in such a way that the tread braking method is used for the driving frame, and the one-axle/one-disk method plus tread braking method is utilized for the trailer bogie, similarly to the case of the conventional JR East commuter train. In addition to this configuration, in response to the reduction in the number of brake axles, the cylinder and diaphragm diameters and lever ratio are increased, thereby meeting the reinforced braking force, as shown in Table 1.

Table 1 Comparison of foundation brake equipment

	AC Train	Series E231
Driving bogie	Tread brake -Cylinder Φ165[mm]×4 - Lever ratio 3.5	Tread brake -Cylinder Φ152[mm]×4 - Lever ratio 3.2
Trailer bogie	Tread brake -Cylinder Φ127[mm]×4 - Lever ratio 2.8	Tread brake -Cylinder Φ114[mm]×4 - Lever ratio 1.5
	Disk brake - Diaphragm Φ220[mm]×2 - Lever ratio 2.4	Disk brake - Diaphragm Φ200[mm]×2 - Lever ratio 2.4

(3) Increase of the air spring spacing on the right and left sides

As increase in the load and braking force is required as explained above, it is necessary to increase the rigidity in the direction of the roll in response to the load to be borne by each car. The increase in the rigidity in the vertical direction of the air spring increases the rigidity of the roll, but riding comfort may be deteriorated. To solve this problem, air spring spacing on the right and left sides is increased 1,980 mm to increase the rigidity of the roll.

(4) Mounting the DDM

Since the AC Train adopts the direct drive traction motor (hereinafter abbreviated as "DDM"), the driving bogie is designed to accept DDM installation. As shown in Fig. 4, the rotary motion of the rotor is transmitted directly to the axle through the joints across the motor. If the DDM is mounted, the weight below the spring is increased and the running safety may be adversely affected. This problem is solved by inserting rubber buffer into the joints, thereby preventing the running safety from deterioration.

It should be noted that, to prevent the DDM from being rotated by reaction-force, a link-like reaction-force receiving rod is used to connect the motor enclosure with the bogie frame side beam in the horizontal direction.

In JR East conventional commuter train cars, the main circuit is grounded by means of a grounding bush on the gear device. In the DDM system, there is no space for installing the grounding brush between the wheels, so an axle end grounding device is used.

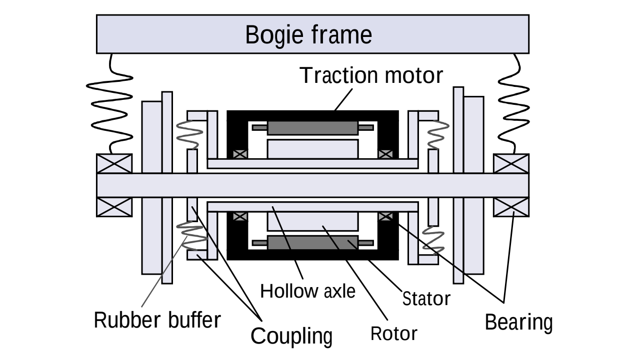

Fig. 4 Installing the DDM

(5) Installation of the car body (Fig. 5)

The car with bolster beam (lower car body) is mounted on the two-point support articulated bogie, and one traction link is used to connect the center pin protruding from the center of the bolster beam with the bogie. The coupling device receiver is located on the top surface of the center of the bolster beam. The coupling device mounted on another car body (upper one) is fitted to this position, and is fixed by a bolt. The coupling device incorporates a spherical bearing, which is used as a node to allow the two car bodies to move.

In the case of the articulated structure using the conventional bogie with a bolster, one of the car bodies is supported at four or six points by means of a center pivot and side bearer. In the case of this structure, the car body is supported at three points by the air spring and coupling device.

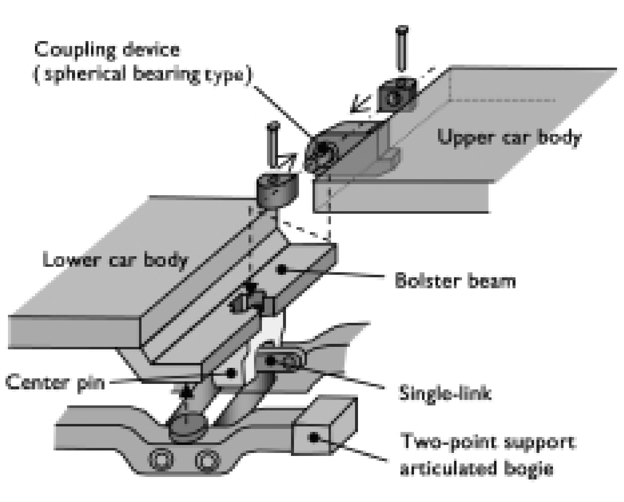

Fig. 5 Mounting the two-point support articulated bogie

3.3 Four-point support articulated bogie

(1) Overview of structure

Each four-point support articulated bogie has four air springs, and each of the car bodies on both sides of the articulated structure is supported by two air springs (Fig. 6). This design increases the number of parts related to air springs such as air springs and leveling valves (hereinafter abbreviated as "LV"), but eliminates the use of the bolster beams protruding between car bodies, as observed in the case of the two-point support articulated bogie. This simplifies the structure on the car body. In Japan, four-point support articulated bogies have been used only in some of the Series 953 Shinkansen high-speed test cars. This is the first time that four-point support articulated bogies are used in the suburban commuter train.

The following describes the characteristics of the four-point support articulated bogie. The strength of the bogie, strengthening of the brake equipment and installation of DDM are the same as those of the two-point support articulated bogie.

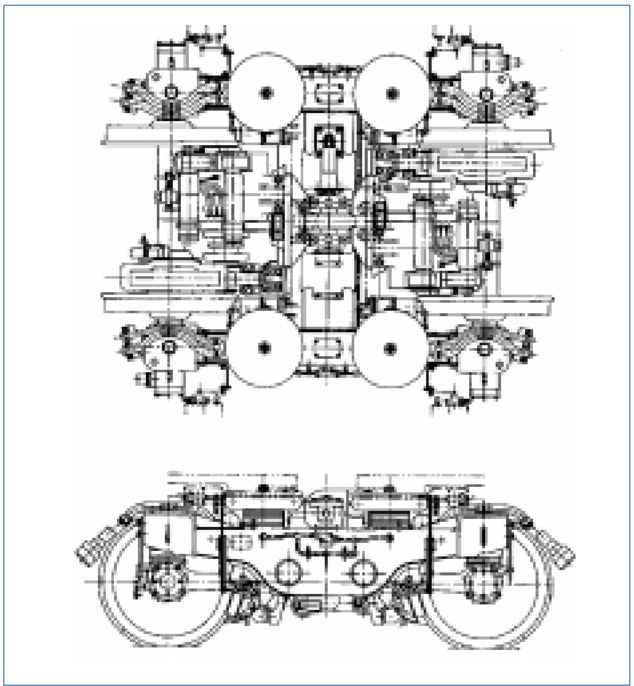

Fig. 6 Four-point support articulated bogie

(2) Spacing of the air springs on the front and back sides

In the case of the four-point support articulated bogie, the spacing of the air springs on the front and back sides is considered to affect the axle weight balance and riding comfort, so it is important to adjust the spacing of the air springs on the front and back sides. In this bogie, in order to minimize such an adverse effect, the spacing is set to 840 mm to the extent that the distance between connecting surfaces of 400 mm can be ensured.

(3) Communicating mechanism of the air spring and control of the height

To avoid imbalance of the axle weight when the air spring has been broken, the air springs in the right/left direction are connected via a differential valve, similarly to the case of the communicating mechanism of the conventional bogie. At the same time, a communicating mechanism using the differential valve is provided for the front/back direction. Consequently, if the air spring at any one position in the bogie is broken, and a big pressure difference between air springs has occurred, then air of all air springs in that bogie is removed to prevent imbalance of the axle weight.

(4) Mounting on car body (Fig. 7)

The car body (lower car body) having a center pin is mounted on the four-point support articulated bogie, and the center pin is connected with the bogie by one link for traction. A receiver of the coupling device is located on the top of the center pin. The coupling device mounted on another car body is mounted on it, and is fixed by bolts. Rubber is press-fitted into the coupling device, and this is used as a node to permit movement between two car bodies. In the case of this structure, the load of each car body is borne by the air spring supporting each car body. Consequently, the coupling device does not bear the load in the vertical direction.

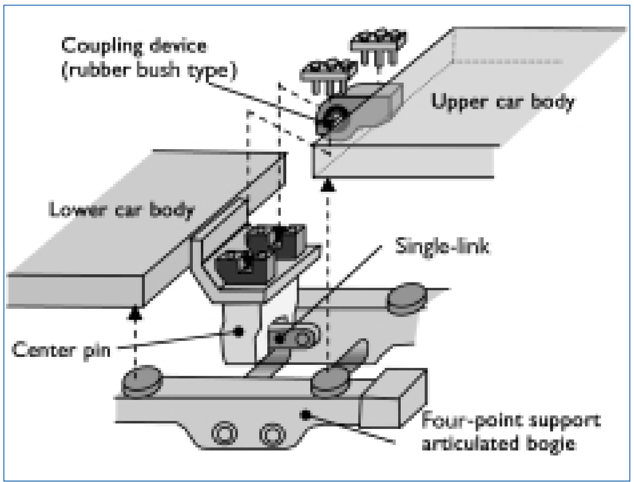

Fig. 7 Installation of four-point support articulated bogie

4 Structure of Articulated Car Body

4.1 Extension of car body

One of the most important issues in the suburban commuter train is to reduce congestion.

In the AC Train, the articulated structure is utilized to expand the on-board space. In the AC Train, the center spacing of the bogie is set to 13,400 mm, which is a standard distance when car body limit is specified. This allows the car width to be expanded to 3,000 mm that is the maximum value of the car.

In the curved portion, the car body between the bogies is pulled inside the curve, and the car body outside the bogie goes outside of the curve. (Fig. 8)

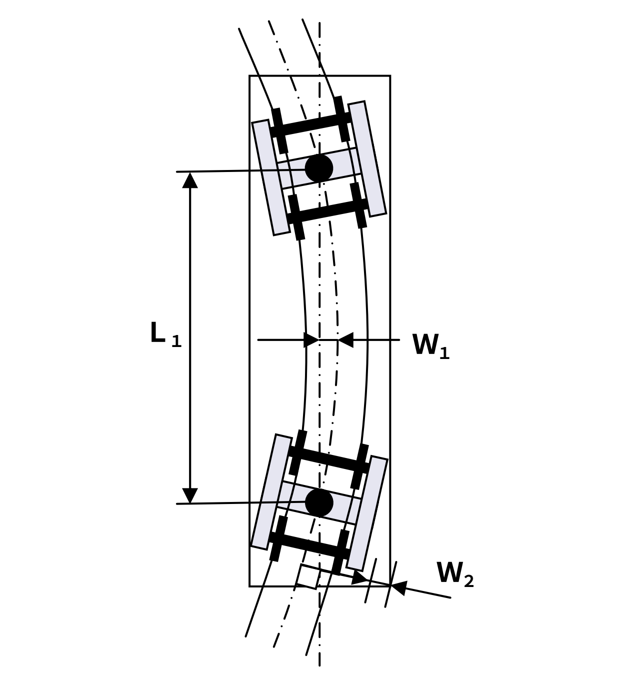

Fig. 8 Deviation on the curve

This can be expressed in Equations (2) and (3).

$$W_1 = R - \sqrt{\{(R-D)^2 - (L_1/2)^2\}} \quad (2)$$
$$D = R - \sqrt{\{R^2 - (L_0/2)^2\}}$$

$$W_2 = \sqrt{\{(R + B/2 - W_1)^2 + (L_2/2)^2\}} - R - B/2 \quad (3)$$

L_0 : Fixed axle distance

L_1 : Distance between bogie centers

L_2 : Car body length

B : Car body width

R : Radius of curvature

W_1 : Deviation inside the curve

W_2 : Deviation outside the curve

The car limit is defined on the straight line. On the curve it can be expanded with consideration given to the above-mentioned deviation. We have used the appropriate equation (4) instead of theoretical equations (2) and (3).

$$W = \frac{22500}{R} \quad (4)$$

W : amount of deviation (mm)

R : curvature radius (m)

This is an equation approximating the amount of deviation with a car body width of 3,000 mm and a bogie center distance of 13,400 mm. This explains the reason why the maximum width of 3,000 mm as the car limit can be obtained when the bogie center distance is 13,400 mm.

The car body length of the suburban commuter train of the current bogie structure is 19,500 mm. Even when the bogie center distance is 13,400 mm, there is a big deviation toward the car ends, and the car body width of 3,000 mm cannot be obtained. In the articulated structure, there is no outward deviation except for the leading car, so there is no need to take this into account. In the AC train, the car body width of 3,000 mm is adopted. It should be noted that the leading portion is designed as a car body of a different structure, and the width of the leading side is decreased to compensate for the outward deviation.

4.2 Structure of corridor connection

In the articulated structure a bogie is located on the coupling portion. So the car bodies at the front and back only rotate about the coupling portion when the car rounds a curve, and no difference of displacement occurs in the right or left direction. Thus, modification has been made to ensure that the coupling portion can be used as passenger space. The width of the corridor connection is maximized so that the corridor connection can be used as space for standing passengers, and a coupling portion having two types of stable floor structures has been provided.

(1) Turntable type

The turntable type is designed in such a way that a disk turning about the coupling portion is mounted, and is maintained at the neutral position by the link mechanism shown in Fig. 9 from the car bodies on both sides (Fig. 10). The displacement angle between the floor surface and turntable can be reduced to half the relative angle between two car bodies. This method is applied to the two-point air spring support position.

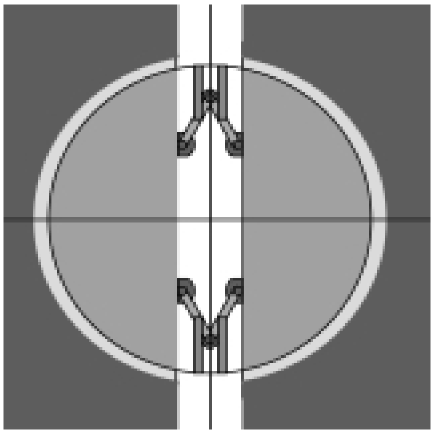

Fig. 9 Turntable type link mechanism

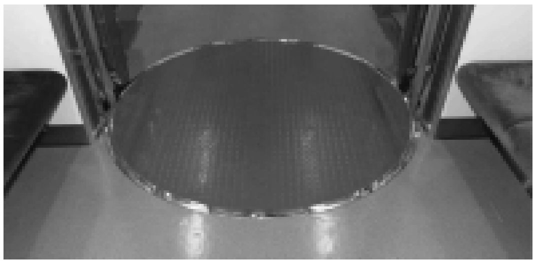

Fig. 10 Turntable type link mechanism

(2) Semicircular apron mechanism

The semicircular apron mechanism is configured so that a semicircular plate is fixed on the car body on one side. According to this method, the displacement angle is double that of the turntable method, but the coupling structure can be simplified (Fig. 11). A panel is provided inside the bellows so safety is ensured when a passenger leans against it. This method is applied to the four-point air spring support portion.

Fig. 11 Semicircular apron mechanism

When a passenger stands on the coupling position, he/she does not feel uncomfortable, according to what we have heard from many people for test. We are planning to make an assessment and verification under the conditions of continuous curved sections.

4.3 Wiring at coupling portions

The car has a great variety of through-cables and wires for electrical circuits, and these cables and wires must be routed from car to car in order to connect the electrical circuits. In the case of articulated structure, the bogie is located on the coupling portion, so it is difficult to use the method that employs the space below the coupling portion as is done in the bogie car. To solve this problem, the AC Train utilizes the following method to route cables car-to-car.

(1) Method for end-to-end routing of cable

End-to-end routing of the cable is provided on both sides of the corridor connection, but the spacing between connection surfaces is as narrow as 400 mm. This issue is overcome by routing the cable in an "S" shape. This method is applied to the two-point air spring support portion.

Fig. 12 End-to-end cable routing (left) and bogie-internal cable routing (right)

(2) Method of routing the cable inside the bogie

The space inside the bogie side beam is used to route the cable. A cable tray is provided inside the side beam. This method is applied to the four-point air spring support portion.

5 Running test

5.1 Overview of the test

To verify the running safety of the AC Train, the following running tests were conducted:

Test period

From February 18, 2002 to March 15

Test line

From Sashioogi to Akabane on the Kawagoe/Saikyo lines

Test speed

Maximum speed: 120 km/h

Speed on curves: basic speed plus 15 km/h

Measurements

The leading cars (TR916), two-point support articulated bogie (DT957) and four-point support articulated bogie (DT958) were subjected to PQ measurement according to the new continuous method to verify the running safety. All three types of bogies used modified arc wheel profile, so the target of derailment coefficient was set to 0.95.

5.2 Test result

There was no problem with safety in regard to derailment. The derailment coefficient was smaller than 0.95 and dynamic wheel unloading load rate was smaller than 80% over the entire line from

Sashioogi to Akabane at the maximum speed of 120 km/h and the maximum cornering speed of the basic speed plus 15 km/h. Also, there was no place where the maximum lateral force exceeded the target value for each curve.

Further, the two-point support articulated bogie and four-point support articulated bogie were provided with the DDM, but there was no remarkable lateral force that might adversely affect the running safety. This is considered to be due to the effectiveness of the rubber buffer in the joint.

To illustrate the examples of the results of testing the running safety, Fig. 13 shows the relationship between the derailment coefficient and speed, and relationship between maximum lateral force and speed on the curve of R = 800 m and C = 95 mm.

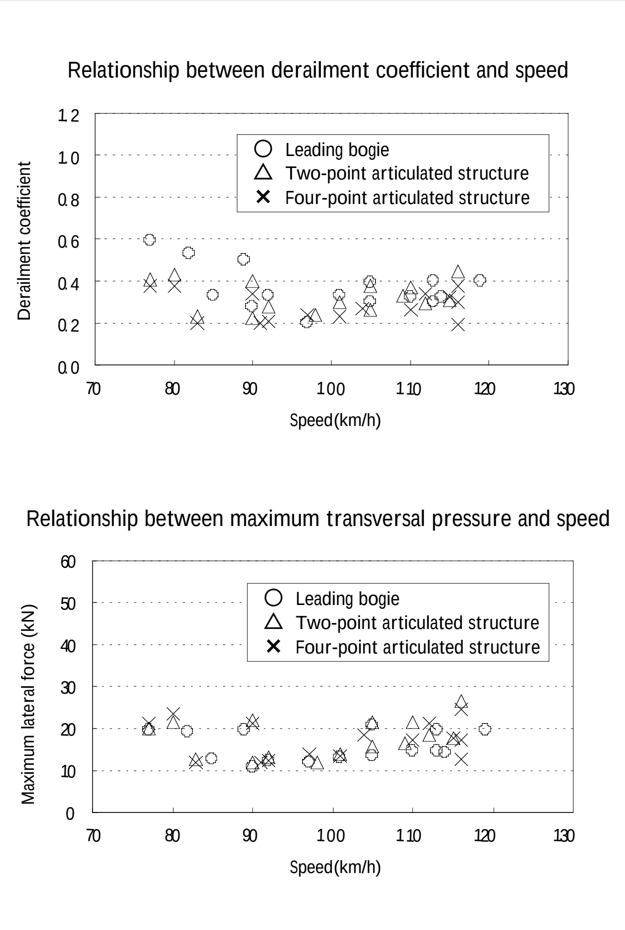

Fig. 13 Derailment coefficient and maximum lateral force (R = 800 m and C = 95 mm)

6 Conclusion

JR East has developed an AC Train of articulated structure as the next-generation suburban commuter train. The following summarizes what has been described above.

(1) The AC Train uses an articulated structure to reduce the car cost and weight through reduction in the number of devices and to expand the passenger space by increasing the car body width.

(2) In order to make a comparative study of the running performances and articulated portion, we have developed two types of articulated structures; a two-point air spring support articulated structure and a four-point air spring support articulated structure.

(3) Running tests were conducted to verify the running safety at the maximum speed of 120 km/h and the maximum cornering speed of the basic speed plus 15 km/h.

Our challenge for the future is to carry out more detailed analysis of the test data and to improve the articulated structure based on the test results, thereby achieving further refinement of the articulated structure.

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