HIGH-SPEED TECHNOLOGY OF SHINKANSEN 300 SERIES

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INTRODUCTION

Tokaido Shinkansen line began its service in 1964 and has contributed Japanese social and economic development since then. On the other hand, its maximum speed was improved only 10km/h, from 210km/h to 220km/h, in 1986.

Central Japan Railway Company (JR Tokai) developed new Shinkansen train, 300 series, to compete with airlines and automobiles. JR Tokai began the service of the 300 series in March 1992 to keep an advantage of Tokaido Shinkansen as a high-speed mass transportation. The 300 series runs at 270km/h and connects between Tokyo and Osaka, 515.4km, in 2 hours and 30 minutes. The 300 series improved its maximum speed more 50km/h than that of conventional Shinkansen trains. To confirm its performance, we carried out a speed improvement test for two years from March 1990.

In speed improvement project of Tokaido Shinkansen line, we have to solve two serious problems, because the line goes through densely populated area. The first is reduction of vibration and noise emission along the line and clearing Japanese environmental restriction. The second is maintenance of completely safe and stabilized service for passengers as much as 100 million per year.

We focused on preservation of environmental conditions primarily, and build a thoroughly light weight train, Shinkansen 300 series, to prevent vibration according to speed improvement. Maximum axle load of the 300 series was reduced to 11.3 ton from conventional train's 16 ton. To reduce its weight, we attempted many try-out. For example, we changed traction unit's component from two cars' unit to three cars' unit, and 16 cars' configuration became 5(M-T-M)+T. The purpose of the rearrangement is to improve train's weight balance and reduce its maximum axle load. One traction unit of 300 series has three heavy electric elements, one transformer and two convertors. We distributed one of these elements to each car, and one traction unit consists of three cars. Trailer car equips a traction transformer and a pantograph as a power supply car.

The light-weight and high-performance technology of 300 series is described below.

Table 1 Main Specification of 300 series New Shinkansen Train

Item	300 series	100 series
1. Train formation	300 series (3-car 1-unit)	

300 series (3-car 1-unit)

Car	1	2	3	4	5	6	7	8 G	9 G	10 G	11	12	13	14	15	16
Symbol	Tc	M1	Tpw	M2	N1w	Tp	M2k	M1s	Tps	M2s	M1H	Tp	M2w	M1	Tpw	M2c
Number of seats	65	100	85	100	90	100	75	68	64	68	63	100	90	100	80	75

Seating Capacity Comparison

Car type	Ordinary car	First class car	Total
100 series	1,153	168	1,321
300 series	1,123	200	1,323

100 series (2-car 1-unit)

Car	1	2	3	4	5	6	7	8 G	9 G	10 G	22	12	13	14	15	16
Symbol	Tc	M'	M	M'	M	M'	M5	TsBO	TsD	M's	M7	M'	M	M'	M	T'c
Number of seats	65	100	90	100	90	100	80	42	56	66	73	100	90	100	90	75

2. Electric system	25 kV ac 60 Hz	
3. Maximum service speed (km/h)	270	220
4. Traction motor output (kW/train)	12,000	11,040
5. Axle load (ton)	Maximum 11.3 tons or less	Maximum 16 tons or less
6. Principal dimensions		
(1) Maximum length (mm)	25,800 (leading car) / 24,500 (intermediate car)	25,800 (leading car) / 24,500 (intermediate car)
(2) Maximum width (mm)	3,380	3,380
(3) Maximum height (mm)	3,650	4,000 (4,490 in case of double-decker.)
(4) Center distance between trucks (mm)	17,500	17,500
7. Carbody structure	Aluminum alloy extrusions	Mild steel
8. Truck	Bolsterless, air-spring suspension type 2-axle truck, gear coupling drive	Bolster, air-spring suspension type 2-axle truck, gear coupling drive
9. Gear ratio	23:68 = 1:2.96	27:65 = 1:2.41
10. Air conditioning and ventilation system	Centralized heat pump air-conditioning equipment, inverter drive scroll compressor, continuous ventilation system with shared pressure releasing unit	Semi-centralized heat pump air-conditioning equipment, reciprocal compressor, continuous ventilation system
11. ATC system	2-frequency system	2-frequency system
12. Powering control	VVVF inverter control using asynchronous motor	Thyristor phase control system using DC motor
13. Braking control	Control subject to adhesive pattern, electric command pneumatic brake, AC regenerative brake (Trailing cars equipped with eddy current brake), all cars equipped with variable load actuator	Control subject to adhesive pattern, electric command pneumatic brake, dynamic brake (Trailing cars equipped with eddy current brake)
14. Auxiliary power supply system	Static inverter: 100 Vac / DC power supply: 100 V Auxiliary transformer: 100 Vac / Tertiarywinding: 440 V	Static inverter: 100 Vac / DC power supply: 100 V Auxiliary transformer: 100 Vac / Tertiary winding: 440 V

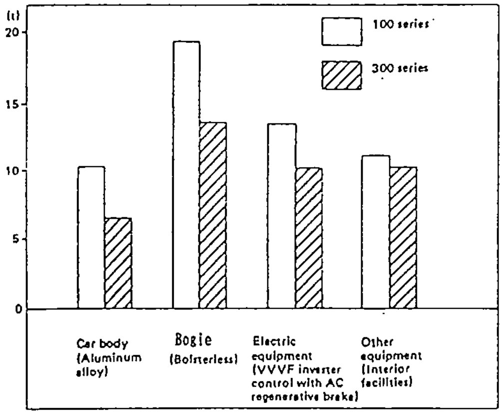


Figure 1 Weight Comparison(Car)

1. ELECTRIC EQUIPMENT

In a development of electric equipment of 300 series, we focused on light-weight and high-performance, needed for high speed train. For success of the development of 300 series, progressed electronic technology contributed very much.

1.1 Light-weight technology of main electric circuit

Reactor elements were eliminated from main electric circuit to reduce its total weight. Instead of the reactor elements, active control, based on recent micro electronic technology, was applied to solve the problems, caused by elimination of reactor elements. Figure 2 shows a diagram of main electric circuit of 300 series. It presents that there is no reactor element in main electric circuit, increasing reactance of traction transformer instead.

In electric control with switching devices such as PWM control, the output includes electric harmonic current inevitably. As for AC electric car, the output of convertor includes harmonic current, whose frequency is doubled that of AC power supply, and it causes the beat phenomenon. To prevent this phenomenon, reactor element was often inserted to main electric circuit and smoothed the output by the passive control. For example, ICE, German high-speed train, uses many reactor elements in main electric circuit to smooth the ripple in the circuit.

Reactor element is so heavy and disadvantageous for light-weight. We eliminated reactor elements in main electric circuit of 300 series, and some problems, such as beat phenomenon and electric saturation of traction transformer, occurred according to the elimination. The control methods against these problems are described below.

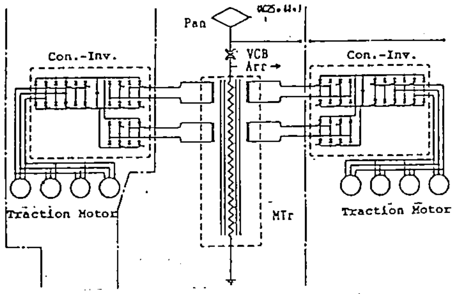


Figure 2 Main circuit diagram

1.1.1 Beatless control

In a process of development of 300 series, beat phenomenon occurred and over current protection for traction motor acted, when the output frequency of convertor comes doubled frequency of power supply. Reactor element is useful for this problem, but it is much disadvantageous for light-weight. Therefore, we applied the beatless control with recent micro electronic technology to this phenomenon.

Figure 3 shows the principle of beatless control. To overcome the beat phenomenon by active control, the pulse width is controlled according to input current. When input voltage increases because of the ripple, the pulse width is controlled to be narrower. On the other hand, when input voltage decreases, it is controlled to be broader. By means of this control method, the input voltage for each phase of traction motor is regulated, and the beat phenomenon is prevented.

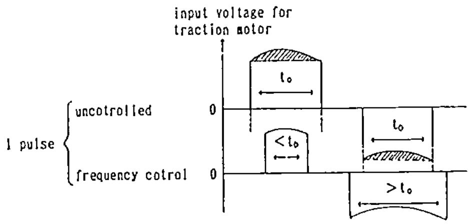


Figure 3 Principle of Beatless control

Figure 4 shows the test result of beatless control. Figure 4 presents output current waveform of inverter around 120Hz. It is observed from Figure 4 that beat phenomenon is not perfectly eliminated. Beat phenomenon can be eliminated perfectly, if the pulse width is controlled in each half wave length, but the output might be instability. As a result of this test, designed output is produced, so, we limited its control within practical level.

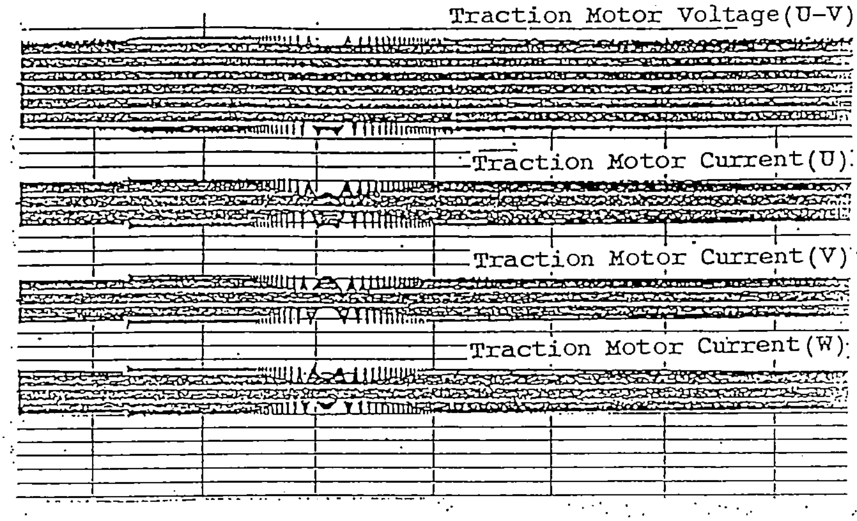


Figure 4 Beat of Traction Moter Current

1.1.2 Electric saturation of traction transformer

In electric main circuit of 300 series, specific reactor element is not inserted in front of convertor, and secondary winding of traction transformer acts to regulate the input current of the convertor. Thus, when the electric saturation occurs, reactance of transformer decreases and the input for the convertor rapidly increases over limitation.

To prevent this problem, the input current for convertor is observed and compared with demand signal, and compensated according to demand signal by real-time control. By means of this control method, in case of the distortion of the secondary voltage waveform, input current waveform is controlled and formed to sinusoidal waveform, and we overcame the problem.

1.2 Light-weight technology of traction motor

1.2.1 Adoption of AC asynchronous motor

DC motor has been used as a traction motor for a long time, because of its easy control and good traction characteristics.

AC asynchronous motor is widely used in industry, because of its easy maintenance and simple structure. We have discussed to adopt asynchronous motor as a traction motor of railway vehicle, but there are many parameters for traction control of asynchronous motor and its control is complicated. Recent micro electronic technology realizes high-speed digital calculation and overcomes these difficulties.

AC asynchronous motor does not need commutation and does not have commutation brush, so, its maintenance becomes easy. Moreover, there is no rotation speed limited by commutation, and its rotation speed is improved up to rolling bearings' performance.

Nowadays AC asynchronous traction motor becomes to be adopted for railway vehicle, because of its easy maintenance. As for 300 series, AC asynchronous traction motor is adopted, mainly because it realizes light-weight traction system.

Light-weight system is required for high-speed train to prevent vibration, noise emission and damage to railway track. The 300 series has totally 40 traction motors per train. Therefore, its light-weight effect is enormous.

1.2.2 The progress of light-weight traction motor

Table 2 shows the progress of light-weight traction motor from 1984 to 1991. The table indicates that we have remarkably reduced the power-weight ratio by 50 percent in several years.

Table 2 Progress of light-weight traction motor

Fabrication year	Power (kW)	Weight (kg)	Weight/Power Ratio	Note
1984	330	750	3.27	prototype
1985	330	650	1.96	prototype
1989	300	400	1.33	mass-pro.
1991	500	475	0.95	tentative

1.3 Trend of traction system

We developed light-weight traction system for Shinkansen 300 series adopted AC asynchronous traction motor. We applied high-speed digital calculation to prevent beat phenomenon and electric saturation. For these accomplishments, recent micro electronic and power electronic technology contributed very much.

Today, AC traction system, composed of voltage type inverter and AC asynchronous traction motor, becomes world standard for traction system of high-speed train. The traction system of 300 series is one of the most progressed systems, because it realized thoroughly light-weight system and applied progressed electronic technology.

2. BOGIE

New bolsterless bogie was developed and adopted for Shinkansen 300 series.

The development of the bolsterless bogie for Shinkansen train began at Railway Technical Research Institute in 1980. Then, we made several prototypes of bolsterless bogie and continued experiments of them. In 1987, we build new bogies to run on the track and carried out endurance test twice with adopted them to conventional Shinkansen train.

On the basis of these test results, new bolsterless bogie for 300 series was developed to realize high stability on high-speed region and marvelous light-weight. Table 3 shows the specification of this bogie.

Table 3 Comparison of Bogie Specification

Series		300		100	
Bogie type		TDT203	TTR7001	DT202	TR7000
Carbody suspension system		Bolsterless type		Bolstered type	
Axle distance (mm)		2500		Same as left	
Wheel diameter (new) (mm)		860		910	
Maximum length (mm)		3420		4200	
Maximum width (mm)		3120		3160	
Center distance (between axle boxes) (mm)		2000		2100	
Standard height of fittings above air spring		1000		1190	
Drive system		Parallel cardan, gear coupling		Same as left	
Brake system	Mechanical	Pneumatic/hydraulic conversion disk brake		Same as left	
	Electrical	Regenerative brake	Eddy current brake	Rheostatic brake	Eddy current brake

2.1 Features of the bogie of 300 series

2.1.1 Light-weight bogie

The features of the bolsterless bogie of 300 series are as follows.

(1) Axle distance, Drive system and Axle box structure are as same as 100 series'.

(2) To reduce unsprung weight, drilled axle, small diameter wheel, and other light-weight devices are adopted. These devices contributed to reduce a damage to track, to progress stability in high-speed region and to reduce rolling noise between wheel and truck.

(3) Bolster anchor, center pin, and side beams are eliminated to reduce unsprung weight and to realize a simple structure and easy maintenance. Because of this simple structure, its running stability can be maintained for a long time.

(4) Axle box suspension with rubber cylinder is adopted, and both end beams are eliminated.

(5) Axle box and gear box are made of aluminum alloy.

(6) Light-weight AC asynchronous traction motor is adopted.

As a result of the try-out, the weight of DT203 bogie of 300 series is reduced by 30 percent less than that of DT202 bogie of conventional 100 series. (Figure 5)

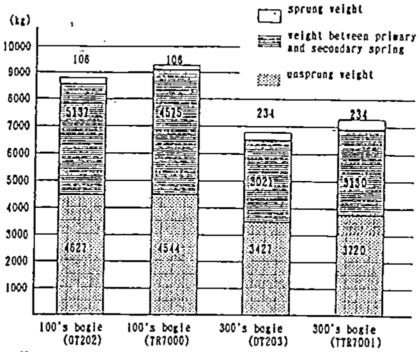


Figure 5 Comparison of bogie weight of 100's and 300's

2.2.2 Running stability on high-speed region

To realize a good balance between running stability on high-speed region and curve transit performance, conventional IS axle box suspension is replaced by the axle box suspension with rubber cylinder. Yaw damper realized stability of bogie's rotating resistance and damping force, and improved its reliability. As a result of these efforts, sufficient and accurate damping force was obtained, and running stability and smooth curve transit performance was improved.

3. BODY STRUCTURE

3.1 Progress of aluminum alloy body for Shinkansen train

Shinkansen's body consists of airtight structure to prevent from pressure change in passenger's room in entering tunnels. Steel is used for body structure, because it is cheaper and easy to weld continuously to construct airtight structure. Thus, all conventional Tokaido Shinkansen train's body is made of iron.

Aluminum alloy structure was applied for experimental trains, type 951 (build in 1969, 2 cars' configuration, maximum speed 286km/h) and type 961 (build in 1973, 6 cars' configuration, maximum speed 319km/h), to realize light-weight body. On the basis of these test results, aluminum alloy structure was adopted for Shinkansen 200 series for Tohoku and Joetu Shinkansen line. Although, manufacturing technology of aluminum alloy was not progressed at that time, it is much improved recently.

3.2 Body structure of 300 series

Body structure is changed from steel to aluminum alloy to reduce its weight. The number of welded points is decreased by using long extruded aluminum parts. Thus, high reliability was realized and its weight was reduced two thirds less than that of steel structure.

As for body size of 300 series, to keep the capacity of passengers, the width is as same as conventional train's. On the other hand, the height is lower than conventional train's (100's 4000mm : 300's 3650mm), although, height of passenger's room is maintained. Thus, light-weight structure, improved aerodynamics, and body with low center of gravity were realized.

The body structure endures the pressure change of 750mmAq and its bending rigidity is over 1.5kg/mm.

Figure 6 shows body structure of 300 series. Long extruded aluminum parts are widely used for body side structure. Roof structure is composed of solid structure with ribs, and the ribs are welded with main structure. Structures are made to be long and thin, such as its width of 600mm, length of 24500mm, and thick of 2.3mm.

Outside plate is mainly made of 6N01, Al-Mg-Si alloy, and main structure is made of 7N01, Al-Zn-Mg alloy. We change the materials according to its strength.

3.3 Other light-weight facilities

There are a number of seats in the car, and the effect of their weight reduction is magnificent. Aluminum alloy and rivets are adopted to lose weight. Thus, the weight of the seat for second class is 12kg per person (conventional's 28kg) and for first class is 20kg per person (conventional's 42kg).

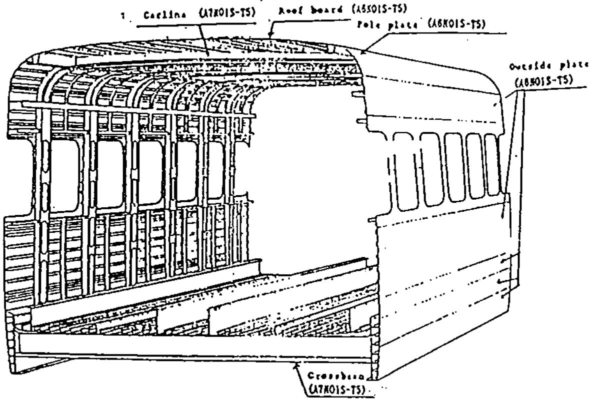


Figure 6 Car body structure

4. COUNTERMEASURE AGAINST ENVIRONMENTAL RESTRICTION

4.1 Requirement for environmental preservation

In speed improvement projects in Japan, we have to solve environmental problems, noise emission, vibration, and shock wave in tunnels inevitably. Although, Governmental restriction level for noise emission is under 70dB(A), it is 75dB(A) provisionally in densely populated area.

The light-weight technology to reduce vibration was described above, and the countermeasures against noise emission are described below.

4.2 Countermeasures against noise emission

Table 4 shows the countermeasures against noise emission. We confirmed these countermeasures by running test and modified the shape of pantograph cover and cable-head cover, and considered the place of pantograph. Thus, we almost cleared governmental restriction in 270km/h operation. The bus line system with two pantographs contributed for noise reduction and prevention of electric saturation of traction transformer.

Table 4 Countermeasures against noise emission

source of noise	Countermeasures
Current collection systems (pantograph etc.)	> Low noise pantograph > Decrease of the number of pantograph (3 equipped, 2 of 3 used) > Current bus line > Cover of pantograph and cablehead
Aerodynamic noise	> Small cross-sectional area of body (low height of body) > Flush and slant nose > Flush surface of the roof > Flush surface of the side windows and doors > Flush surface of the bottom of body (covered equipment)
Wheel and track	> Reduction of axle load
Structure (bridge,etc.)	> Reduction of axle load

5. SAFETY DEVICES FOR HIGH-SPEED OPERATION

5.1 Automatic Train Controller (ATC)

ATC has been used as a safety device for Shinkansen operation since Tokaido Shinkansen started. Conventional ATC system had 6 signals, 220, 170, 120, 70, 30, and Stop, sent by single frequency method. We changed this system for 300 series' operation. Two more signals, 270 and 255, are added, according to improvement of operation speed and the system was changed to double frequency method.(Table 5)

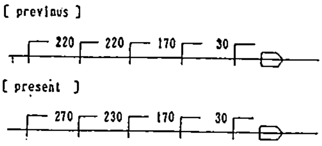
In this double frequency method, ATC receives both main frequency and sub frequency from ground facilities and judges from mixed information and presents signal in the cab. By this method, reliability is improved, because train stops, if it does not receive both frequencies by accident or noise.

Figure 7 and 8 show the signal pattern of ATC. As for 300 series, the braking distance from 270km/h to 230km/h and that of from 230km/h to 170km/h are almost the same as that of conventional train's 220km/h to 170km/h. Thus, 300 series' operation is realized on the present signal blocking system.

Table 5 ATC double frequency system

Sub-frequency(Hz) / Master frequency(Hz)	12.0	16.5	21.0	27.0	32.0	38.5
10.0	220	270	Switch signal	*230	255	03 Signal
15.0				170		
22.0	120					
29.0	70					
36.0					30	
41.5						
Halt signal Signal 30 x Point P 900 Hz (down) 840 Hz (up) No signal	 RI 03 02					

Legend:* indicate the currently used 220 signal.
Note that this signal is replaced with the 220 signal for the 0 and 100 series and with the 230 signal for the 300 series.



Fugure 7 Signal Pattern

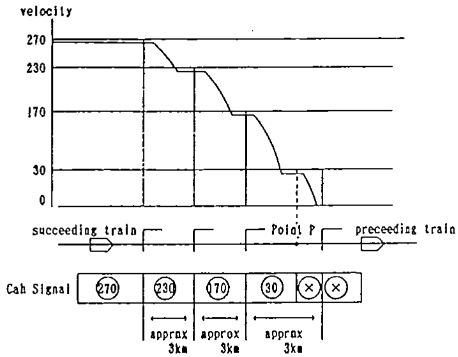


Figure 8 Signal Pattern in approaching preceeding train

Legend:Point P:The point of stopping operation. 30 signal changes to stop signal on this point P when the preceeding train exists next blocking section.

6. CONCLUSION

JR Tokai developed Shinkansen 300 series and performed tests of vehicles, tracks, electric facilities and environmental problems for speed improvement. The 300 series achieved new Japanese speed record, 325.7km/h, in February 1991. Then, the endurance test of approximate 280,000km was carried out, and the maintenance standards of vehicle, track, and electric facilities were confirmed. At last, the service of the 300 series started in March 1992.

The Shinkansen 300 series adopted state-of-the-art technologies for main electric circuit, body construction and bogie. We are sure that Shinkansen 300 series becomes an origin of the new Japanese high-speed railway age.