Development of the superconducting maglev vehicles on the Yamanashi test line

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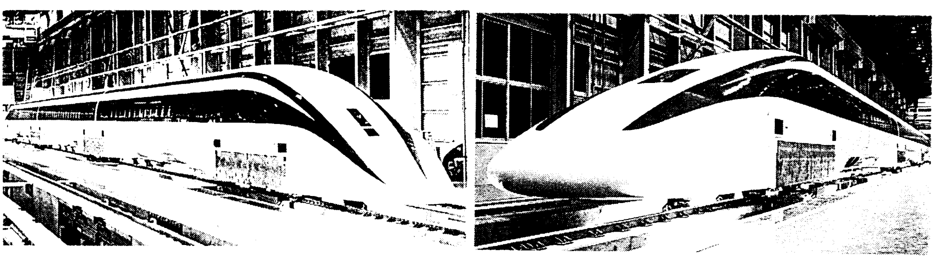
Abstract

We have been developing the superconducting magnetic levitation (Maglev) systems since 1962. In the spring of 1995 the vehicles for the first train set on the Yamanashi Test Line, named the "MLX01" type, were completed and were moved to the Yamanashi depot. The first train set is a 3-car unit. The constitution of vehicles is an articulated bogie system. The train can run levitated at over 500 km/h. An important feature of the exterior is the nose shape of the head cars. The head car for Kofu is named the "Double Cusp" style, and the head car for Tokyo is named the "Aero-wedge" style, each being a shape with superior aerodynamic performance.

This paper describes Maglev vehicles and various equipment of the first train set on the Yamanashi Test Line.

1. Introduction

The construction of the superconducting Maglev system on the Yamanashi



Mc1 ("Double Cusp" style) Mc2 ("Aero-Wedge" style)

Fig.1. Outside view of the "MLX01" Yamanashi Maglev Vehicles

Test Line was started in 1990. In the final plan, the length of this test line is 42.8 km. Now 18.4 km of this length is being constructed as an initial test area. And the vehicles for the first train set which is a 3-car unit were completed in the spring of 1995. We have two train sets, and the second one which is a 4-car unit will be designed this year.

The Yamanashi Test Line is the final stage for confirming the possibility of commercialization of Maglev System. The testing items are as follows:

(1) High-speed stable run at 500 km/h with safety and comfort.

(2) Reliability and durability of vehicles and ground facility/equipment including superconducting magnets.

(3) Structural standards specifying a minimum radius of curvature, the steepest gradient ,etc.

(4) Distance between track axes taking account of two trains passing each other.

(5) Vehicle performance related to tunnel cross section and the pressure fluctuations in tunnels.

(6) Turnout performance.

(7) Environmental conservation.

(8) Multiple train traffic control system.

(9) Operation and safety system, and maintenance standards.

(10) Control system between substations.

(11) Economy of construction and operation.

The beginning of test runs is scheduled for the spring of 1997.

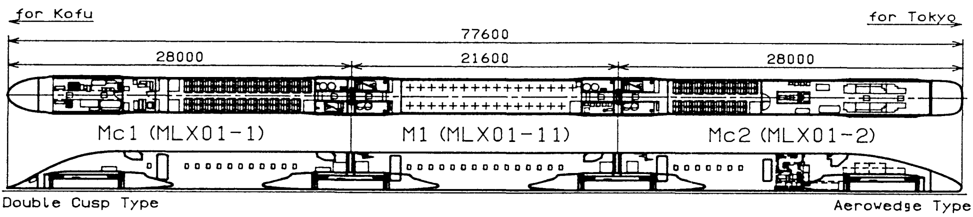


Fig.2. Outline of the First Train Set named the "MLX01" type

2. Outline of the First Train Set on the Yamanashi Test Line

The vehicles on the Yamanashi Test Line are named the "MLX01" type. The first train set consists of three cars, the car No.1 is the head car for Kofu (Mc1), the car No.2 the standard middle car (M1), and the car No.3 the head car for Tokyo (Mc2). The train set is an articulated bogie system. The vehicles can run levitated at over 500 km/h (experimental maximum speed 550 km/h). The service brake system is a regenerative brake, and there are two types of regency brakes, provided: a wheel disk brake and an aero -dynamic brake (Fig.2).

An important feature of the exterior is the nose shape of the head cars. Mc1 is named the "Double Cusp" style, and Mc2 the "Aero-wedge" style,

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Table 1. Technical details of MLX01

Maximum Speed		500 km/h (Maximum Test Speed 550 km/h)		
Model		Mc1	M1	Mc2
Passenger Capacity		46	—	30
Max. Gross Weight		29 t	20 t	30 t
Body	Length	28,000 mm	21,600 mm	28,000 mm
	Width	Body Part 2,900 mm, Bogie Part 3,220 mm		
	Height	Levitated Run 3,280mm (Wheel Run 3,320 mm)		
	Cross-Sectional Area	8.9 m^2 (Vehicle/Tunnel Ratio 0.12)		
	Construction	Aluminum Alloy Semi-Monocoque Structure		
	Joint Method	Rivet	Spot Weld	Rivet + Weld
	Nose Type	Double Cusp	—	Aero-wedge
Distance between Bogies		21,600 mm		
Bogie Type		SCM-Rigidly Mounting Type 4-Point Support Bogie		
Superconducting Magnets		4 Coils per Side Same Poles on Both Sides (700 kA)		
Auxiliary Power Unit		DC 600 V		
		—		Ni-Cd Battery Gas Turbine Power Unit
Power Unit of Control		DC 100 V		
		Ni-Cd Battery		
Air Compressor		SF-JF-C1000LA	—	SF-JF-C1000LA
Air Conditioner		Ram Air Ventilation System		Ram Air and Fan V.S.
Brake Systems		Regenerative Brake (Primary) Wheel Disk Brake, Aerodynamic Brake		
Etc	Seat Arrangement	2 x 2, Pitch 880 mm Reclining Seat with Rotation		
	Entrance Door	Upward Sliding Door (Sky Door)		
	Service Equipment	Information Display for Passenger Announcement System		

Table 2. Terms of body load

Item	Mc1	M1	Mc2
Vertical Load	205 kN	151 kN	210 kN
Compression Load at Body End	392 kN		
Airtight Load	Maximum: Outer Pressure -20 kPa ~ + 13 kPa		
	Repeat: Outer Pressure -17 kPa ~ +11 kPa		
Correspond-ence of bending force	Over 1.4 GN·m^2		

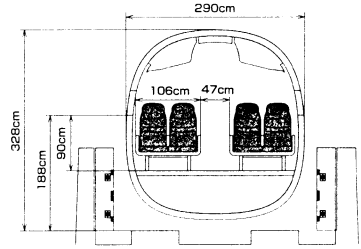

Fig.3. Cross-sectional area

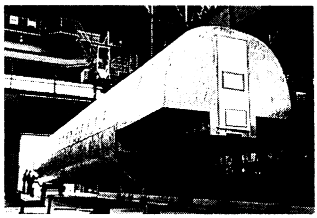

Fig.4. Trial body (H2 body)

each having superior aerodynamic performance. Both head cars are equipped with seats, baggage racks, etc. for passenger trial riding, and M1 is designed exclusively for use as an experimental car.

3. Details of Development and Applications to Vehicles

3.1 Development of the super lightweight body

(1) Reduction of body weight

We have decided cross-sectional area and body structure for the super lightweight body as follows:

A quadratic conical curve (Fig.3), which is nearly a circle and different from the box shape of ordinary trains, is adopted to make the stress flat against the airtight load.

The cabin section adopts the semi-monocoque structure to share the vertical load and compression load and mainly to be effective against airtight load. It is different from usual trains as a base frame structure.

(2) Manufacturing of trial bodies

Various trial lightweight bodies were manufactured to perform various load tests including airtight and fatigue load tests. And then the sufficiency of durability was verified before designing the Yamanashi Maglev vehicles (Fig.4).

3.2 Improvement of aerodynamic characteristics

(1) Development of nose shapes

The nose section length was decided to be 9.1 m to reduce the cross-section area ratio, which reduces aerodynamic drag, aerodynamic noise, and micro -pressure waves in tunnels. Simulating by CFD (Computational Fluid Dynamics) and performing many tests in wind tunnels, a formal shape of the Maglev vehicles has been developed. Finally two nose shapes are selected out of many proposed shapes and completed as the most ideal shapes for aerodynamic performance. The air drag coefficients (C_D) of both shapes are under 0.1. Especially, the "Double Cusp" style is superior in controlling the separation of boundary layers when coupled at the extreme tail end of the train, and the "Aero-wedge" style is superior in reducing micropressure waves in tunnels and capacity of equipment (Fig.6).

(2) Fairing of an articulated bogie

Reducing the resistance from pressure at the articulated bogies is important in reducing the aerodynamic drag. Therefore, a fairing (fig.7) was installed to make a smooth transition in cross-sectional area from the body to the bogie, and the gap between the body and bogie is filled with a movable fairing.

3.3 Countermeasure for aerodynamic noise

The causes of noise are the steps, projections, gaps, etc. of the body surface. The flatness of the body surface was examined as follows:

(1) Outer hood between the coupling of bodies; the outer hood which is made of a urethane block is installed between the coupling of bodies to smooth the body surface from front to end.

(2) The flush-surface installation of the window; the window glass is installed on the body with a step difference of 1 mm to the body surface.

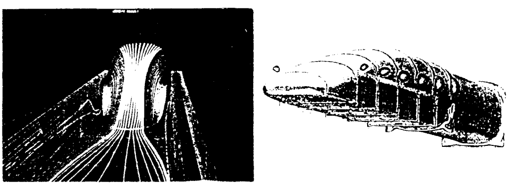

Fig.5. Simulating by CFD of Nose Shapes

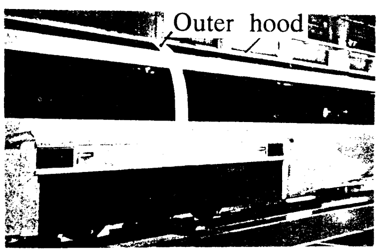

Fig.6. Flatness of body and bogie

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(3) The steps of the door; the door is of an upward sliding door type, with a step difference of 2 mm between the door leaf and body surface.

3.4 Magnetic shield

Magnetic shields were installed on the body to shield the passengers from the magnetic fields of the superconducting magnets. The materials and arrangement of the magnetic shields were examined to reduce the weight and to make shield performance effective.

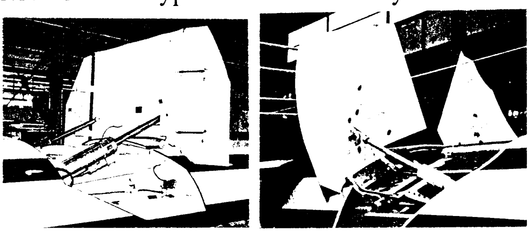
Industrial-pure steel and electromagnetic steel were selected for the magnetic shield. These materials are superior to other materials in magnetic density, magnetic penetration rate, processing, costs, etc.

The most suitable thickness and arrangement of the shields were decided from various analyses and a full-scale mock-up. It was then possible to reduce the strength of the magnetic field to under 2 mT in the cabin, and the weight of the shield to under 1.4 t in the standard middle car.

3.5 Aerodynamic brake system

An aerodynamic brake system is adopted as one of the emergency brake systems. This system operates when the primary brake system (a regenerative brake) malfunctions during high-speed running. It can act in under 1.5 sec by the opening command. The power source of this brake is oil pressure which is supplied from the bogies . Therefore it is installed on the top of each car at the bogie positions (Fig.7). There are two types of this brake system as follows:

(1) "One-board type"; it consists of a main panel with subpanels on both sides of the main panel. This type has two features, a projection area (3.7 m^2) which is a small cut-out area of skin, and a small curve of the panel which reduces the brake drag difference between forward and backward run .



One-board type Two-board type
Fig.7. Aero-dynamic brake system

(2) "Two-board type"; it has two independent panels, each panel projection area is 1.85 m^2 . The lock mechanism is built into each actuator. This type is very simple.

3.6 Ventilation and air-conditioning system

A ventilation system basically uses a ram air intake at high speed (over 180 km/h) and uses a ventilation fan at low speed. And the passenger ear discomfort from a sudden change in cabin pressure through tunnels is controlled by tuning the intake and exhaust valves while monitoring the cabin pressure against the change of outer pressure. There are two types of the ventilation systemas follows:

(1) "Ram air ventilation system"; it is a ventilation by a ram air intake

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system, which shifts between intake and exhaust by the running direction, takes in the running air from a pair of ram air intakes facing each running direction. And this system has a low pressure fan for low speed running (Fig.8).
(2) "Ram air and fan ventilation system"; it uses both a ventilation fan and a ram air intake at high speeds to obtain fresh air, and uses a ventilation fan when the train is at a low speed and at a stop (Fig.9).

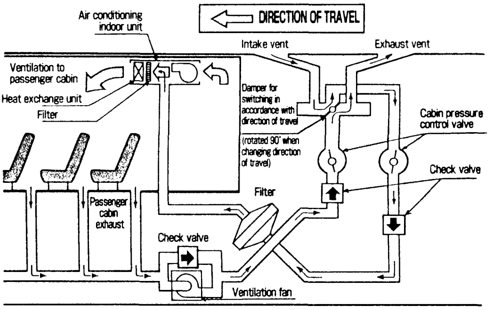

Fig.8. Ram air ventilation system

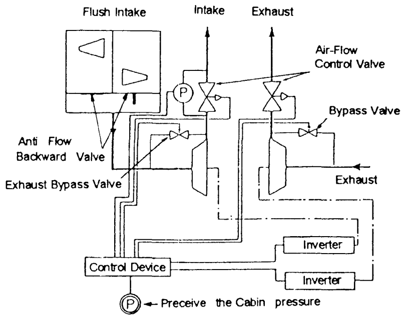

Fig.9. Ram air &fan ventilation system

3.7 Others

We have tried to reduce the car body weight as follows:
(1) Abolition of cab; a cab which looks like an ordinary train is not necessary for Maglev vehicles, because Maglev systems are active track systems. Then a front glass and a magnetic shield for the cab are abolished to reduce the weight.
(2) Small window; the window glass is made as small as possible without causing passengers a feeling of occlusion, by securing the vision through a window area of 400 mm height x 300 mm width and by adequately setting the seating pitch.
(3) Light weight of equipment; an optical fiber sends various information, aluminum for the body of devices and a type of air pipe, a complex honeycomb for interior panels, etc., are used.

4. The Head Car for Kofu (Mc1)

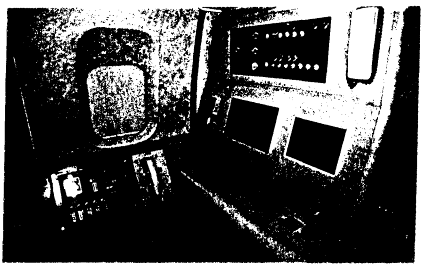
Fig.10. Crew cabin of Mc1

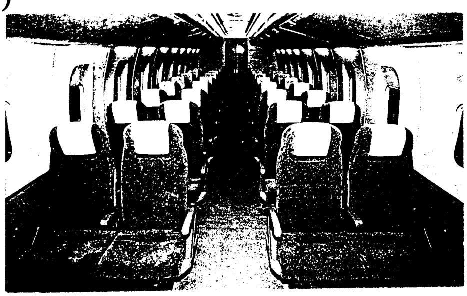
Fig.11. Passenger room of Mc1

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4.1 Features of Mc1

Mc1 is designed as a controlling car and trial riding car. Therefore many controllers and a monitoring system are installed in the head section (mainly in the crew cabin), for example the on-board central controlling system, battery for controllers, antennas and devices for the radio system, converters, inverters for power supply to the bogie system, etc. There are 46 seats, stowage bins resembling those in airplanes, and an air conditioning system in the cabin section for trial riding (Fig.10,11).

4.2 Car body structure of Mc1

The car body construction of Mc1 consists of 3 sections: the head section, the cabin section (passenger room), and the articulated section. The passenger room, gangway at the articulated section, and crew cabin are airtight structures (Fig.18).

The material of the body structure except for the magnetic shield is duralumin whose types are 2024 and 7075, which are the same materials as in aircraft bodies. The car body of Mc1 is fabricated using rivets which are the same as in aircraft bodies.

The cabin section structure consists of 3 cylindrical blocks. Each block consists of a top panel, a bottom panel, and 4 side panels.

The frame pitch is 440 mm, which is half the seating pitch. The stringer pitch is 170 - 220 mm. The head section consists of the nose cone and the crew cabin. The nose cone is composed of framework to form the "Double Cusp," and of another skin with a thickness of 4.06 mm (0.16 in) to withstand birds and pebbles that may strike the body. The crew cabin is of the same structure as the cabin section. A coupler, a buffer, antennas, marker lights (head and tail lights), and CCD cameras are housed in it.

Mc1 has two aerodynamic brake systems, which are installed on top of the crew cabin and articulated section.

5. The Head Car for Tokyo (Mc2)

Fig.12. Passenger room of Mc2

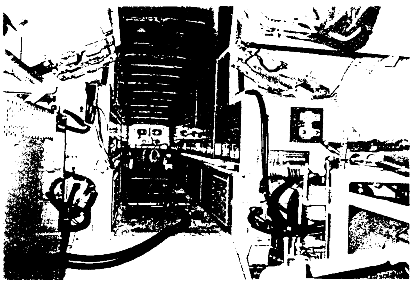

Fig.13. Equipment room of Mc2

5.1 Features of Mc2

Mc2 is designed to serve as an electric power supply car and a trial riding car. Therefore much electric equipment are installed in the head section (mainly in the power source room), for example battery cells, an electric power generator using gas-turbines, a main DC/DC converter, inverters for electric power supply to the bogie systems, etc. The power source room has no windows. There are 30 seats, racks, and an air conditioning system in the cabin section for trial riding (Fig.12, 13).

5.2 Car body structure of Mc2

Mc2 consists of 3 sections: the head section, the cabin section (passenger room), and the articulated section . All sections are built by several methods, and they are connected to each other by riveting or welding. The passenger room and gangway at the articulated section are airtight structures. The power source room is not airtight (Fig.18).

The material of the body structure except for the magnetic shield is an aluminum alloy. The aluminum alloy is of types 5083, 7N01, and 6N01, and the outside shells of the cabin section and power source room are made of 6N01 aluminum extrusion.

The cabin section structure consists of 6 cylindrical blocks: a top panel, a bottom panel, and 4 side panels. The frame pitch is 440 mm and the stringer pitch is 100 mm. The panels of the cabin section are extrusions with stringer. These panels are planed by a skin miller to 2.3 mm to 1 mm in thickness, in order to reduce the weight by more than 15%. This is called the "pocket process." Panels and frames are connected by riveting . The head section structure consists of the nose cone and power source room. The head section is constituted of frames and stringer, which are joined by arc welding to form the "Aero-wedge." The top of the nose cone is made of FRP for use as a nose cover (Fig.14). The nose cover was confirmed for strength in the event of hitting birds at 500 km/h. A coupler, a buffer, marker lights (head and tail lights), and CCD cameras are housed in it.

The power source room is of the same structure as the cabin section, but the outside shells and frames are joined by spot welding . The articulated part is constituted of frames and plates which are joined by welding.

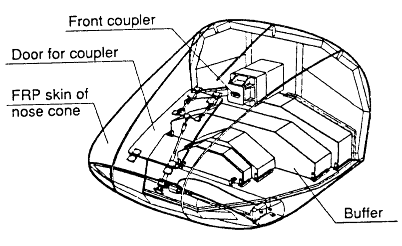

Fig.14. Nose cover of Mc2

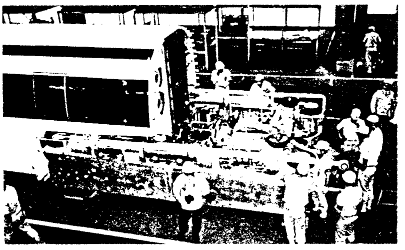

Fig.15. Articulated bogie with Mc2

6. The Standard Middle Car (M1)

6.1 Features of M1

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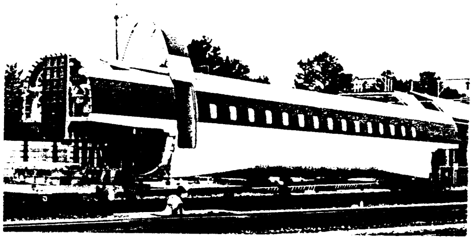


Fig.16. Outside view of M1

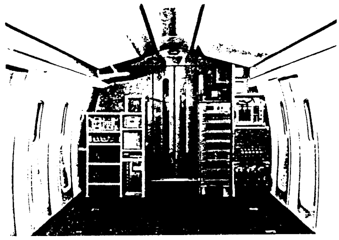
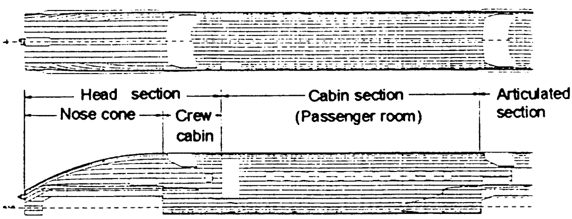


Fig.17. Cabin layout of M1

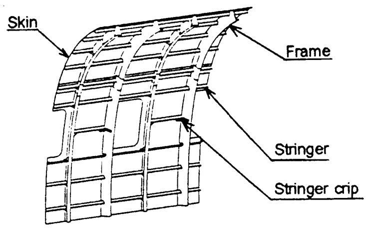
M1 will be used only as an experimental car. Therefore it is not equipped with passenger seats, racks, etc. But an air conditioning system is installed in the cabin section for the measurement operator (Fig.16,17).

6.2 Car body structure of M1

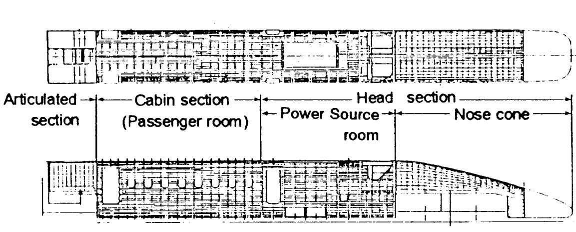
M1 consists of 3 sections: the cabin section and the articulated sections at both ends of the body (Fig.18). The material of the structure except for the magnetic shield is an aluminum alloy, of types 5083, 7N01, and partly 7075 duralumin.



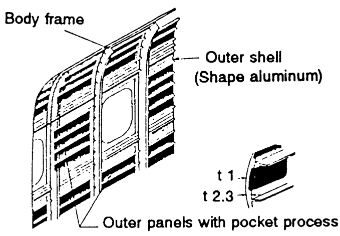
Structure of Mc1



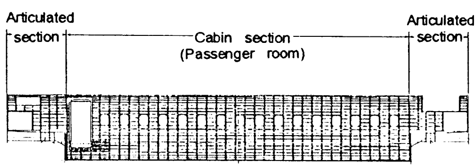
Cabin structure of Mc1



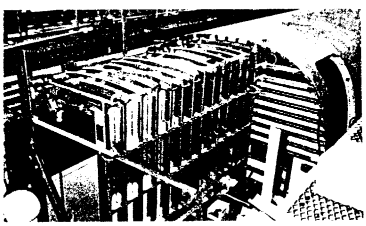
Structure of Mc2



Pocket process of the cabin structure of Mc2



Structure of M1



Articulated part of M1

Fig.18. Car body structure of Mc1, Mc2 and M1

The cabin section structure consists of 4 longitudinal blocks: a top panel, a bottom panel, and 2 side panels. Each block is constituted of outside skin with frames and stringer which are made of aluminum shapes. The blocks are joined by spot welding or riveting at the outside skins and frames. The M1 body structure features a seamless outside shell, 16 m long. The articulated section structure of M1 is just like Mc2. It is constituted of frames and plates. The aerodynamic brake system is installed on the top of this section on the Tokyo side.

7. Closing Remarks

The car body weight is reduced by about 50 % of the Shinkansen Series 300 which is one of the newest trains. But it is necessary to save the weight further to reduce the running energy and to decrease the burden of the ground structure and ground coils.
It is hoped that the success in the items of the various tests will enable revenue Maglev operation in the near future.

The development of the superconducting Maglev systems has been subsidized in part by the Japanese Ministry of Transport.

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