Analysis of the anti-kink hydraulic system and running mode of low-floor trams

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Abstract: Based on the analysis of the structure and operation mode of low-floor urban trams, the structure, principle, components and technical parameters of the anti-kink hydraulic system which specially set up were described, and the application characteristics of the hydraulic system technology were pointed out.

1 Introduction
Urban road-rail transit system with low-floor urban trams is a new type of urban transportation system. The maximum volume of such system was 6–8 times that of the bus system. Compared with the metro rail system, the low-floor urban trams system has great advantages in project cost, riding comforts and curving behaviour [1, 2].

In order to improve the passing ability, vehicle stability and riding comfort of the low-floor tram on the small-radius curve, the anti-kink hydraulic system was installed between two-bodies and bogie in one unit. The anti-kink function is the vehicle’s capacity to keep identical yaw-angles between two-modules in one unit during operating, which ensures an optimum body running envelope curve for all kinds of lines. The damping function refers to lateral damper buffering effect on the car body, to provide a comfortable riding experience for passengers.

2 Low-floor trams and running kink

2.1 Low-floor trams structure
Unlike classic rail vehicles, which have two bogies under each car body, low-floor trams have only one bogie under the centre of each body to improve the curve passing capacity and realise the function of 100% low floor.

It usually forms a four-module grouping form of three moves and one drag as shown in Fig. 1, which is expressed as follows:

\[ M_1 + M + M_2 = T; \]

where \( M \) is the motor vehicle module, \( M_c \) is the motor vehicle module with driver’s cab, \( T \) is the trailer with the pantograph, \( = \) is the hook, \( + \) is the single articulated hinge joint, \( ++ \) is the double articulated joint. The two-vehicle bodies of the same single hinge unit can only rotate in the horizontal plane around the hinge centre. The two vehicles of the same single articulated hinge unit can only rotate in the horizontal plane around the articulated hinge centre, while the two vehicles of \( T \) and \( M \) are connected by a double articulated hinge, which does not completely limit the freedom of the vehicle body of the two single articulated hinge units.

2.2 Kink of low-floor trams

The low-floor trams of the above structure can be regarded as a split of the car body of the classic structure rail car, realising that a single-car body matches up with single bogie, and realising the connection between the front and rear car bodies with a single articulated hinge joint. The single articulated hinge joint endows extra rotational freedom between the front and rear bodies, which can realise the unique kinking movement between the bodies of low-floor trams, and improve curving behaviour. However, the redundant degree of freedom between the front and rear bodies will make the position of the vehicle uncertain when passing the track curve of small radius, excessive bending between the bodies is easy to occur, which will make the vehicle exceed the driving limit and reduce the stability of the vehicle.

At the same time, in the case of vehicle traction or braking system failure, the running state of low-floor trams also has uncertainty [5, 6].

In order to avoid the above problems, it is necessary to install an anti-kink hydraulic system with variable damping between the body and the bogie in the design of low-floor trams, so as to improve the damping and stiffness between the body [7, 8].

Fig. 1 Structure of low-floor trams

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3 Anti-kink hydraulic system structure and principle

3.1 Structure

The low-floor trams composed of four modules are equipped with an independent hydraulic system at the single articulated hinge joint between Mc1 and T modules and between the M and Mc2 modules. In train driving, in order to control the entire hydraulic system, also equipped with the main control valve group, auxiliary valve group, buffer valve group, controller and other components, valve block internal layout of pressure relay and switch solenoid valve. The driver can monitor the anti-kink hydraulic system.

The complete anti-kink hydraulic system is shown in Fig. 2. Its main components are as follows [9]:

Eight control cylinders: To realise the power control of bogie rotation, cylinder diameter of 30 mm, the working stroke of ±110 mm and the working pressure of 15 MPa is maintained.

Two buffer cylinders: To eliminate the pressure pulsation of the hydraulic system and realise the stable transmission of force. The cylinder diameter of 390 mm, rod diameter of 30 mm, piston working stroke of ±14 mm, the working pressure of 6.8 MPa is maintained.

A set of disc springs with the stiffness of 2740 kN/m are arranged on both ends of the buffer cylinder. Disc springs are used to ensure proper stiffness between front and rear bodies when the train is running normally. The compression of the disc spring group by piston can relieve the pressure impact caused by vehicle bending. The piston rod and cylinder of the buffer cylinder are connected with the front and rear body, respectively.

Two sets of main control valve blocks: Each set of main control valve block contains two relief valves DBV1 and DBV2 with the set pressure of 10.5 MPa, and DS1 and DS2 are two normally open low-voltage relays with the set pressure of 0.6 MPa. It also contains two normally closed high-voltage relays DS3 and DS4 with the set pressure of 10 MPa. The diameter of the damping valve R1 between the Z1 and Z2 pipelines is 0.2 mm.

Four groups of auxiliary valve blocks: The pressure of the unloading valve is set as 0.8 MPa and the diameter of the attached damping hole is set as 1.5 mm.

Two sets of auxiliary valve blocks: Normally open two-way solenoid valve. When the pressure relay attached to the valve detects the pipeline pressure exceeds 10.5 MPa, the valve realises the switch of the oil circuit.

Two accumulators: The charging pressure is 2 MPa, the working pressure range is 0.8–3.2 MPa. When a line Z1 or Z2 is over pressurised, the relief valve DBV1 or DBV2 will be opened and the high-pressure oil will be recharged into the accumulator. Instead, the accumulator will return oil to the pipeline.

3.2 Principle

3.2.1 Normal mode: Under the normal mode, the low-floor trams operate in a variety of ways, such as linear track, arc track, transition curve track and s-shaped curve track, among which the trams run on transition curve track is the most representative, as shown in Fig. 3.

When the tram is driving forward to the right on the track of right turn transition curve shown in Fig. 3, under the constraint of the track, the bogie in front of the tram will generate a clockwise angle α1 relative to the body 1 (the body 1 rotates counterclockwise relative to the bogie), and push the piston rod of the control cylinder to move. The high-pressure oil in cavities 1A2 and 1B2 of control cylinder flows to 2A1 and 2B2 forcing the oil in cavities 2A2 and 2B1 to flow to 1B2 and 1A1. In this way, the volume of oil in or out of each cylinder cavity is equal during tram running, the rotation angles of the front and rear body α1 and α2 will always be equal. In this way, when the low-floor trams pass through the transition curve, the front and rear body will maintain a certain bending angle, which is conducive to passing through the curve track.

3.2.2 Fault mode: Traction fault and brake fault are the main fault forms in the running of low-floor urban rail vehicles. In the event of traction or braking fault, even if the tram is travelling on a straight track, kinking between bodies will occur due to yaw. If the
anti-kinking hydraulic system is still working in the above normal mode, the buffer cylinder will be in a non-aligned position for a long time, resulting in an intensification of yaw. Working in these conditions, it is necessary for the anti-kink system to increase the joint stiffness to alleviate the problem between the front and rear body.

In the fault mode, the auxiliary valve MV3 realises position switch, the hydraulic system is changed into the form shown in Fig. 4. The pipelines Z1 and Z2 communicate directly with each other and Z2 disconnect the buffer cylinder, while other parts of the system are in the same normal mode.

When the front vehicle is driving straight to the right and yawing, there is no delay in the pressure transmission between the high and low-pressure cavity of each control cylinder and pipelines, and also no delay in the rotation of body relative to the bogie. The anti-kink system has good synchronisation. As the buffer cylinder is shielded, the hydraulic system will produce a large pressure impact and the motion stability is reduced.

3.2.3 Rescue mode: In order to avoid the vacuum pressure caused by initial pressure of the system is <3.2 MPa, the anti-kinking hydraulic system, in normal mode, was installed a throttle valve R1 between the pipelines Z1 and Z2 [10, 11]. Throttles with small apertures have less impact on bending systems in normal mode. However, if the vehicle system is kink under static load, the high-pressure oil in the system will continue to flow through the bypass throttle to the low-pressure loop, which is bound to cause the bending between the bodies and is not conducive to the rescue operation. Therefore, the hydraulic system of rescue mode must be changed.

In rescue mode, the throttle R1 in the main control valve block is disconnected due to valve MV1 or MV2 being closed, so that pipelines Z1 and Z2 are completely disconnected. In addition, the buffer cylinder also continues to be interrupted from the system as a result of fault mode. In this mode, the anti-kink hydraulic system provides maximum stiffness, effectively resisting the kinking between bodies, even the tram is pushed or pulled. As there is high rigidity when the trams pass the curve in rescue mode, the high-pressure impact will be produced in the hydraulic system, and the stability of the vehicle will be reduced significantly. In rescue mode, the low-floor trams should not run at higher speed (Fig. 5).
4 Conclusion

The anti-kink hydraulic system of low-floor trams has unique performance, which is shown in the following aspects:

(i) The anti-kink hydraulic system enables low-floor rail cars to have a definite outer limit when they are running, ensuring the safety of vehicles.

(ii) After connecting with the buffer cylinder, the control cylinder can control the yaw of low-floor trams. The non-linear damping provided by the buffer valve block can attenuate the lateral vibration of the body and improve riding comfort.

(iii) Anti-kink hydraulic system can adjust the connection stiffness between front and rear body by cutting off the connection between buffer cylinder, throttle valve and other components, which can provide sufficient guarantee for driving safety in fault and rescue mode.

Low-floor trams have been put into operation in Line HAIZHU, Line LONGHUA and Line NINGBO. Its modular structure makes the vehicle with high reliability and the maintainability, and ensures the efficient and safe operation of the urban rail transit system.

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6 References

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