Chapter 2
Analysis on Lock Problem in Frontal Collision for Mini Vehicle

Ce Song, Hong Zang and Jingru Bao

Abstract To study the lock problem in the frontal collision test on a kind of mini vehicle's sliding doors, this paper performs stress analysis on the lock mechanism of the sliding doors, and puts forward improvement methods. Through the theoretical calculations and frontal collision tests, this paper has verified the effectiveness of the improvement methods, and it provides the theoretical reference for the new vehicle models in the design stage.

Keywords Frontal collision · Sliding door · Lock mechanism · Acceleration

2.1 Introduction

Vehicle frontal collision is a common kind of vehicle collision accidents. From the early contact between the vehicle and the collision object to the collapse and deformation of vehicle structure, it takes totally about 100 ms (0.1 s). Because the time is extremely short, energy changes rapidly during the collision process, it has a great influence on the structure and motion state of the vehicle.

The earliest implementation in China was CMVDR 294 *The Protection of the Occupants in the Event of a Frontal Collision for Passenger Car*. In 2014, a mandatory national standard GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle* was approved and released, which

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put forward detailed stipulations about the technical requirements and the test methods for vehicle frontal collision test.[1]

The car door latch system is composed of the latch, the lock striker, the internal and external operating mechanism, and the lock operating mechanism. The car door latch system is an important safety component of car body. According to GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle*, the test requires that the door is closed but unlocked, and the technical requirements concerning the car door latch system include:

1. During the test, no door shall open;
2. During the test, no locking of the locking systems of the front doors shall occur;
3. After the impact, it shall be possible, without the use of tools: to open at least one door, if there is one, per row of seats (this is only applicable to the vehicles having a roof of rigid construction).

Wherein, requirement 1 is only related to the strength and resistance to inertia load of the car door latch system. It is required in detail in GB 15086-2013 *Motor Vehicles' Door Locks and Retention Components Performance Requirements and Test Methods*, so this paper will not do any in-depth analysis.

Requirement 2 and 3 are both related to the lock performance of the car door latch system, and "it shall be possible to open at least one door" in requirement 3 means that at least one door can be unlocked from the outside of the car.

2.2 Classifications of Car Doors and Car Door Latch Systems

According to different unlocking modes, the car doors (excluding the rear doors) are usually classified into two categories: the hinged doors and the sliding doors; accordingly, the car door latch systems can also be classified into the hinged door latch system and the sliding door latch system. Figures 2.1 and 2.2 are the diagrammatic sketches for the hinged door and the sliding door and the corresponding door latch system respectively.

As shown in the figures, the hinged door latch system and the sliding door latch system have the same function. Both have the functions of internal unlocking, external unlocking and locking. However, they differ in structures. In the hinged door latch system, the external operating mechanism is directly connected with the latch; while in the sliding door latch system, the distance between external operating mechanism and the latch is long, which makes the external operating mechanism cannot be directly connected with the latch,so a switching mechanism is needed to transmit motions to the latch. In addition, the locking function of the

[1]Li [1].

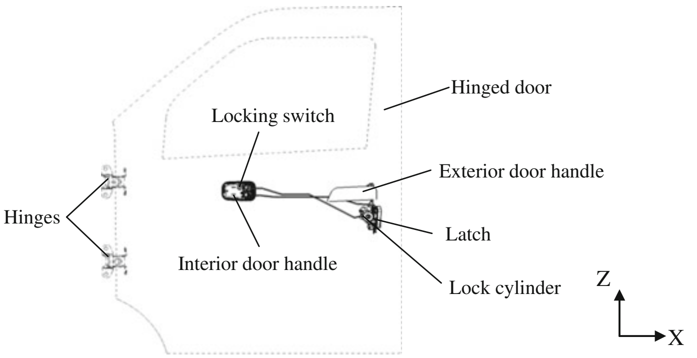

Fig. 2.1 Hinged door and door latch system

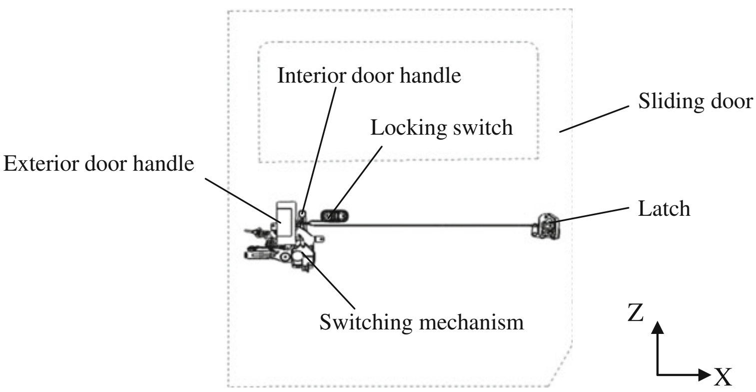

Fig. 2.2 Sliding door and door latch system

hinged door latch system is integrated with the latch, while the locking function of the sliding door latch system is integrated with the switching mechanism.[2]

A company produced a kind of mini vehicle with front doors as hinged doors and rear doors as sliding doors. During the frontal collision test, both of the left and right sliding door latch systems are locked, which does not meet the requirement of GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle* (it shall be possible to open at least one door for per row of seats).

[2]Huang [2].

2.3 Stress Analysis on Sliding Door Latch System

2.3.1 Acceleration Analysis on the Vehicle's B Pillar

The acceleration of B pillar is an important parameter in the vehicle collision test. Because B pillar plays a supporting role in both the front doors and rear doors, the acceleration of B pillar can reflect the acceleration of vehicle doors, and then it can be used to analyze the stress of the door latch system.

Figures 2.3 and 2.4 respectively describes the acceleration curve of the left and right B pillars in the frontal collision test for the mini vehicle. During the collision, both of the maximum acceleration of the left and right B pillar are 50 g. According to the car check after the test, both of the positions of left and right sliding doors have not changed, and the metal structure of the door and the door latch system have not yet been deformed or damaged. Therefore, it can be confirmed that during the collision, the maximum acceleration of the left and right sliding door latch system is both 50 g, the same as that of B pillar.

2.3.2 Stress Analysis on the Sliding Door's Lock Mechanism

The lock mechanism is an independent part in the door latch system. The lock mechanism of the sliding door latch system for the mini vehicle is integrated with the switching mechanism, and the structure is shown in Fig. 2.5. The lock mechanism is composed of lock switching panel, torsion spring and connecting rod, and

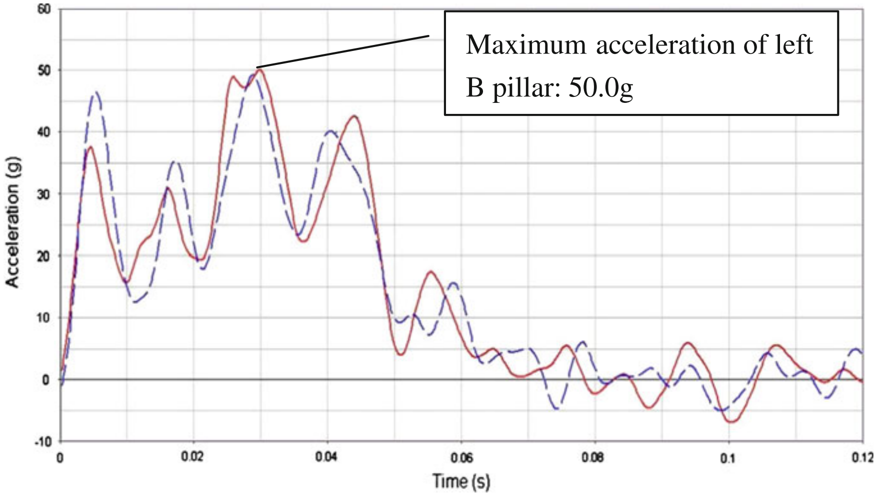

Fig. 2.3 Time curve for the acceleration of left B pillar

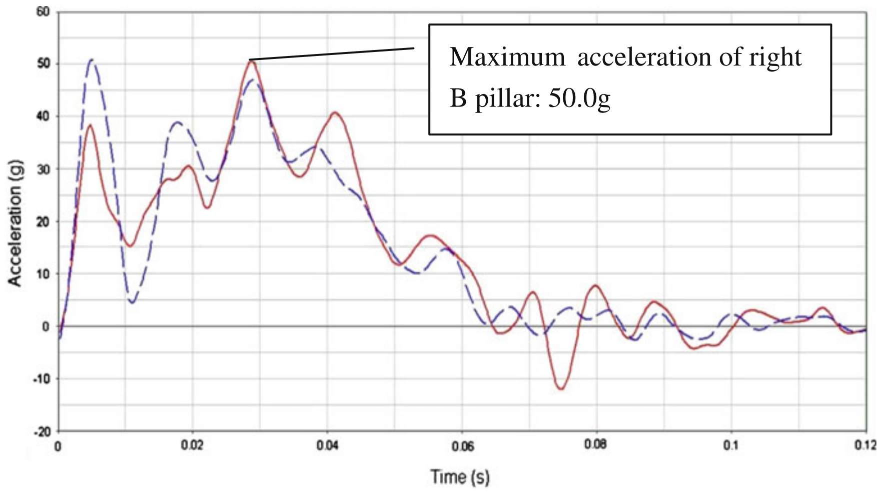

Fig. 2.4 Time curve for the acceleration of right B pillar

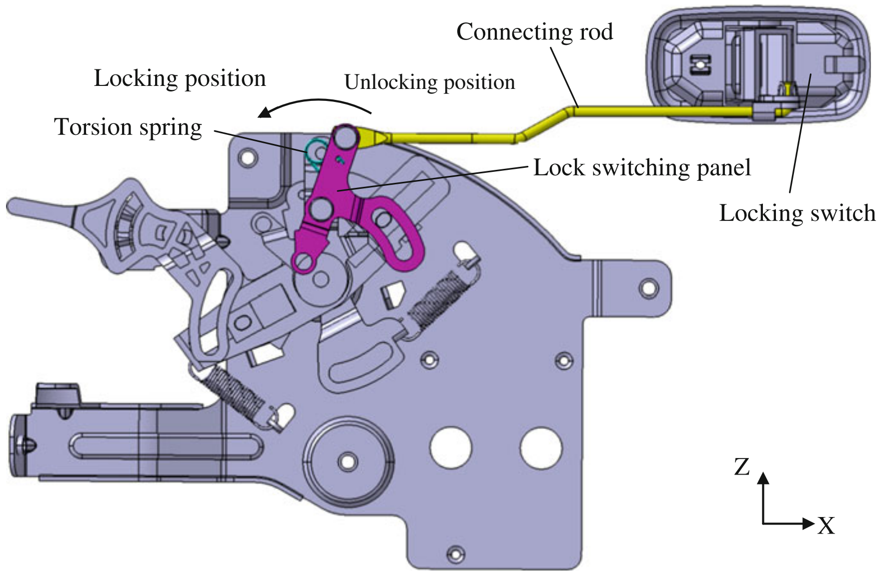

Fig. 2.5 Structure of the switching mechanism

it is connected with the locking switch. During the collision, the lock switching panel is turned from the unlocking position to the locking position as a result of the inertia effect, which makes the left and right sliding doors locked.

This paper conducts stress analysis on lock switching panel in state of unlocking. According to D'Alembert's principle, it transforms the dynamics system during the

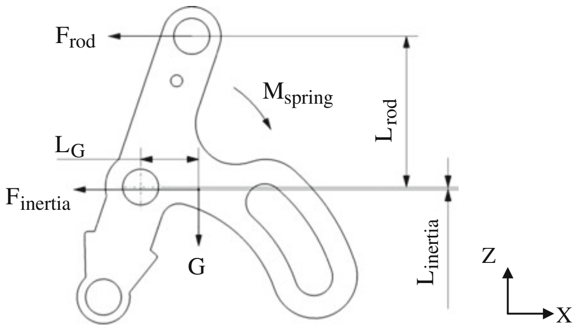

Fig. 2.6 Stress analysis on the lock switching panel during the frontal collision

collision process to the static system, so during the collision process, the stresses on lock switching panel include gravity G, inertia force $F_{inertia}$, connecting rod thrust F_{rod}, and torsion spring torque M_{spring}. Of which, the gravity's arm of force is L_G, the inertia force's arm of force is $L_{inertia}$, and the connecting rod thrust's arm of force is L_{rod}, as shown in Fig. 2.6.

It is known that the mass of lock switching panel m = 0.01 kg, the mass of connecting rod m_{rod} = 0.015 kg, the gravity's arm of force L_G = 9.817 mm, connecting rod thrust's arm of force L_{rod} = 25.579 mm, inertial force's arm of force $L_{inertia}$ = 0.419 mm, and torsion spring torque M_{spring} = 102.316 N·mm.

Suppose that the maximum acceleration in frontal collision is "a", according to the stress analysis in Fig. 2.6, if the sliding door is not locked, it needs to be satisfied:

$$\begin{aligned} & F_{rod} \cdot L_{rod} \leq M_{spring} + F_{inertia} \cdot L_{inertia} + G \cdot L_G \\ & \text{Therefore: } m_{rod} \cdot a \cdot L_{rod} \leq M_{spring} + m \cdot a \cdot L_{inertia} + m \cdot g \cdot L_G \end{aligned} \tag{2.1}$$

$$a \leq \frac{M_{spring} + mgL_G}{m_{rod}L_{rod} - mL_{inertia}} \tag{2.2}$$

Put the known quantities into Formula (2.2), it can be concluded that $a \leq 271.83\ m/s^2 \approx 27.2\ g$.

Through calculation and analysis, the lock mechanism of the sliding door of the mini vehicle can only endure the frontal collision acceleration of 27.2 g, and cannot meet the collision requirement of 50 g.

2.4 Improvement Plans for the Sliding Door's Lock Mechanism

During the vehicle frontal collision process, the collision acceleration is much greater than the gravity acceleration, so the gravity of the parts can be neglected. According to Formulas (2.1) and (2.2), there are three factors affecting the collision acceleration that the lock mechanism can endure:

1. Inertia moment of lock switching panel $F_{inertia} \cdot L_{inertia}$;
2. Torsion spring torque M_{spring};
3. Connecting rod thrust moment $F_{rod} \cdot L_{rod}$.

Because the connecting rod needs to meet the strength requirement and the arrangement requirement of the sliding door's lock system, it cannot be changed. Therefore, it can only adjust the inertia moment of lock switching panel ($F_{inertia} \cdot L_{inertia}$) or torsion spring torque (M_{spring}) to improve the endurance capacity of the lock mechanism to the frontal collision acceleration.

2.4.1 *Plan One: Adjust the Torsion Spring Torque*

According to the stress analysis, increasing the torsion spring torque(M_{spring}) can improve the endurance capacity of the sliding door's lock mechanism to the frontal collision acceleration. According to Formula (2.1), it can be concluded that:

$$\begin{aligned} &M_{spring} = n\left[M_{spring}\right] \geq n(\ F_{rod} \cdot L_{rod} - F_{inertia} \cdot L_{inertia} - G \cdot L_G) \\ &\text{Therefore, } M_{spring} \geq n(m_{rod} \cdot a \cdot L_{rod} - m \cdot a \cdot L_{inertia} - m \cdot g \cdot L_G) \end{aligned} \tag{2.3}$$

Here n is a safety factor and is generally taken as 1.2–1.3. During the frontal collision process, the maximum acceleration is a = 50 g. Put the known quantities into Formula (2.2), it can be concluded that:

$$M_{spring} = n\left[M_{spring}\right] \geq 1.2 \times 188.77 = 226.52\ \text{N} \cdot \text{mm}$$

After adjusting the torsion spring torque, under normal condition, when the lock switch is operated by manual, the lock switching panel will only endure the gravity G, external operation force $F_{operation}$, and torsion spring torque M_{spring}, as shown in Fig. 2.7. Here L_G and $L_{operation}$ respectively represent the arm of force of gravity G and the arm of force of operation force $F_{operation}$.

According to the stress analysis, it can be concluded that:

$$\begin{aligned} &F_{operation} \cdot L_{operation} \geq M_{spring} + G \cdot L_G \\ &\text{Therefore, } F_{operation} \geq \frac{M_{spring} + GL_G}{L_{operation}} = \frac{M_{spring} + mgL_G}{L_{operation}} \end{aligned} \tag{2.4}$$

Here $L_{operation} = L_{rod} = 25.579$ mm, put the known quantities into Formula (2.4), it can be concluded that: $F_{operation} \geq 9$ N.

According to the requirements of automobile ergonomics, the operation force of internal buttons in the driver's cab is recommended for 4–5 N.[3] After adjusting

[3]Du [3].

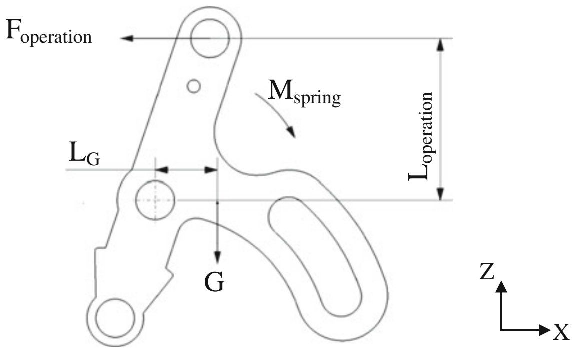

Fig. 2.7 Stress analysis on the lock switching panel under normal condition

torsion spring torque, it does not meet the requirements of ergonomics, so it is necessary to subjectively evaluate the operation force.

In addition, with respect to the electric door locks, after increasing torsion spring torque, the motor load will be enlarged thereupon, the risk does exist, so it still needs to do the reliability test again.

2.4.2 *Plan Two: Adjust the Inertia Moment of the Lock Switching Panel*

As shown in Fig. 2.6, when the centroid of the lock switching panel is below the spin axis, its inertia moment constitutes resistance during the frontal collision process, which is advantageous to endure the acceleration of vehicle frontal collision. According to the stress analysis on the lock switching panel, increasing the inertia moment of the lock switching panel ($F_{inertia} \cdot L_{inertia}$) can improve the endurance capacity of the sliding door's lock switching panel to the frontal collision acceleration.

According to Formula (2.1), it can be concluded that:

$$F_{inertia} \cdot L_{inertia} \geqslant F_{rod} \cdot L_{rod} - M_{spring} - G \cdot L_G \tag{2.5}$$

When $F_{inertia} \cdot L_{inertia} \geq F_{rod} \cdot L_{rod}$, Formula (2.5) can be tenable eternally, and in theory, the sliding door's lock mechanism can endure infinite frontal collision acceleration.

Assuming that the maximum acceleration in the frontal collision is "a", because $F_{inertia} \cdot L_{inertia} \geq F_{rod} \cdot L_{rod}$, it can be concluded that:

$$\begin{aligned} & m \cdot a \cdot L_{inertia} \geqslant m_{rod} \cdot a \cdot L_{rod} \\ & \text{That is, } m \cdot L_{inertia} \geqslant m_{rod} \cdot L_{rod} \end{aligned} \tag{2.6}$$

To increase the inertia moment of the lock switching panel, it needs to increase the mass (m) or the arm of force of inertial force ($L_{inertia}$) of the lock switching panel, so it can add clump weight at the lower part of the spin axis, which can not only increase the mass (m), but can also make the centroid position of the parts downward and increase the inertial arm of force ($L_{inertia}$). Meanwhile, it also needs to make sure that the arrangement space and the movement space of the lock switching panel can meet the requirements.

Figures 2.8 and 2.9 respectively reflect the structural contrast and stress contrast before and after the improvement for the lock switching panel. After the improvement, clump weight is added at the lower part of the lock switching panel,

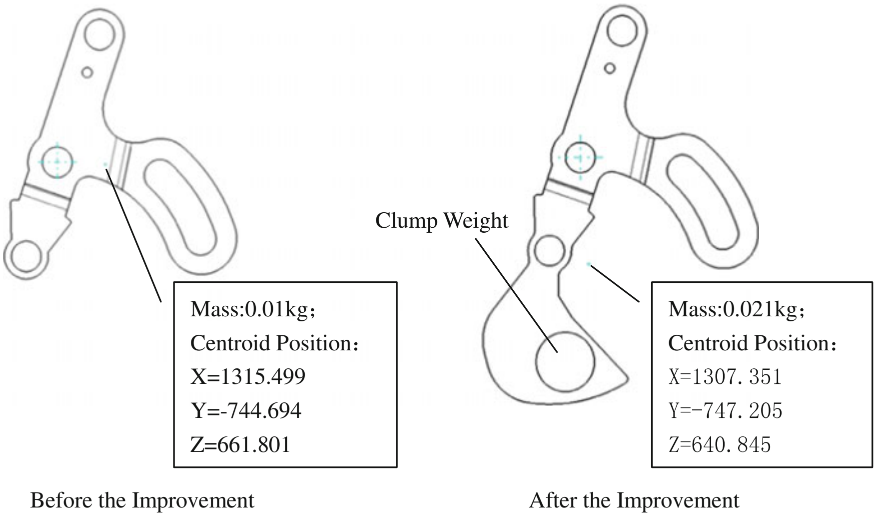

Fig. 2.8 Structural contrast of the lock switching panel

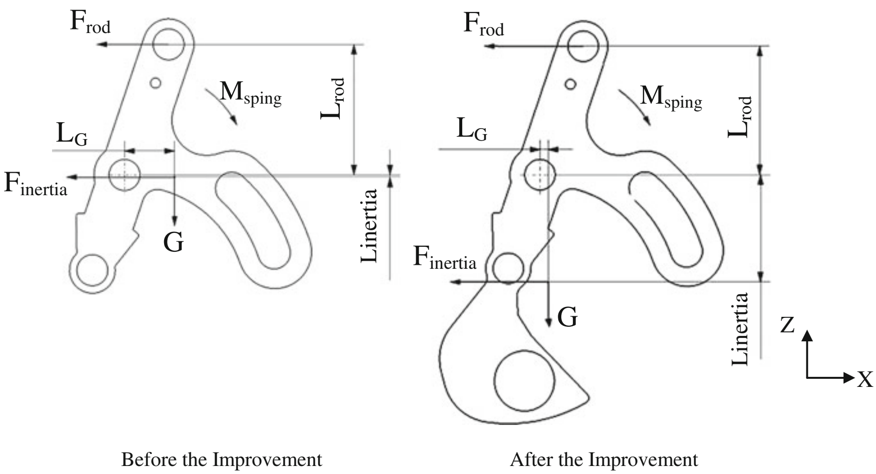

Fig. 2.9 Stress contrast of the lock switching panel

mass m = 0.021 kg (0.011 kg increased). At the same time, centroid position is lowered, which makes the arm of force of inertial force $L_{inertia}$ = 21.375 mm (20.956 mm increased), and gravity's arm of force L_G = 1.669 mm (8.148 mm decreased).

$$\text{After the improvement,}\ m \cdot L_{inertia} = 0.021 \cdot 21.375 = 0.43;$$
$$m_{rod} \cdot L_{rod} = 0.015 \cdot 25.579 = 0.38.$$
$$\text{It can be concluded that :}\ m \cdot L_{inertia} > m_{rod} \cdot L_{rod}$$

It meets the requirement of Formula (2.6), and in theory, makes the sliding door's lock mechanism endure infinite frontal collision acceleration.

Put the known quantities into Formula (2.4), it can be concluded that the operation force of locking switch after the improvement is:

$$F_{operation} \geq (102.316 + 0.021 \times 10 \times 1.669)/25.579 = 4.01\text{N}$$

It meets the requirements of automotive ergonomics.

In order to ensure that the vehicle's operation performance will not be influenced, plan two is adopted to improve the sliding door's lock mechanism of the mini vehicle, the improved switching mechanism of the sliding door is shown in Fig. 2.10.

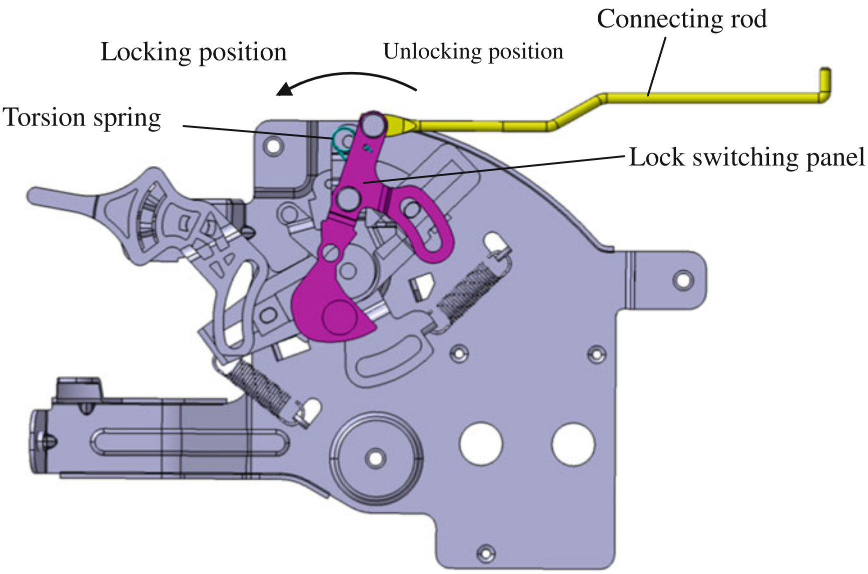

Fig. 2.10 Improved structure of the switching mechanism

2.4.3 Test Verification

Theoretical calculation cannot fully verify the improvement effect, and it still needs to be verified by experiment finally. Install the improved left and right sliding door switch mechanisms on the testing car, and implement the frontal collision test again. The test is carried out in a state designated strong test lab (the same as the first test), and the test conditions are set up in accordance with the requirements of GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle,* as specified in Table 2.1:

During the test, the maximum acceleration of B pillar is 50.3 g. After the test, the structure of the rear of the vehicle's A pillar has not been significantly deformed. Front doors and rear sliding doors can be unlocked normally, and each door has not been locked, which meets the requirements of 4.2.4 and 4.2.5 in GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle*. The effectiveness of the improvement plan is verified. Test status is shown in Fig. 2.11.

Table 2.1 Test conditions for vehicle frontal collision

Test conditions	Specific requirements
Test environment	In accordance with the requirements of 5.1.1–5.1.3 in GB11551-2014
Test vehicle	Normally produced vehicles; install improved left and right sliding door switching mechanisms; no other special modifications
	In accordance with the requirements of 5.1.4 in GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle*
State of the Door	Closed but unlocked; in accordance with the requirements of 5.1.4.3.5 in GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle*
Test speed	50.4 km/h; in accordance with the requirements of 5.4 in GB11551-2014 *The Protection of the Occupants in the Event of a Frontal Collision for Motor Vehicle*

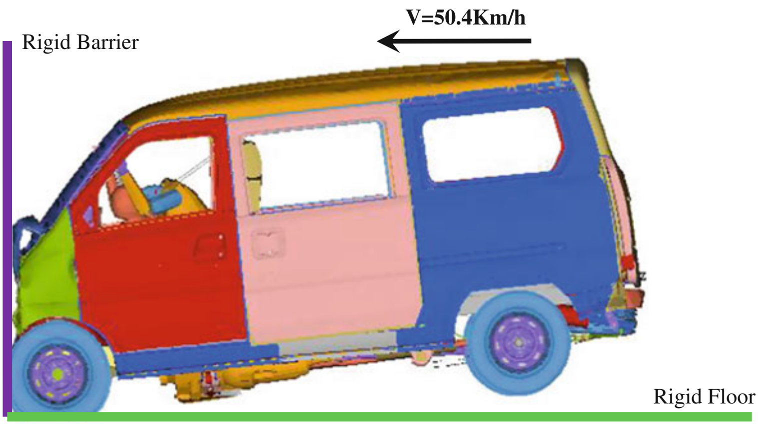

Fig. 2.11 Mini vehicle frontal collision

2.5 Conclusion

1. To study the lock problem in the frontal collision test on a kind of mini vehicle's sliding doors, this paper performs stress analysis on the lock mechanism of the sliding doors, and puts forward improvement methods. The working principle of hinged door latch system is the same as that of sliding door, and it can also be analyzed and improved in this way;
2. The reason why the lock system is locked during the frontal collision process is that the lock mechanism in the lock system cannot endure the collision acceleration;
3. The endurance capacity of the lock mechanism to the frontal collision acceleration is related to the torsion spring torque and the inertia moment of lock switching panel;
4. The way of increasing the torsion spring torque can improve the endurance capacity of the lock mechanism to the frontal collision acceleration, but it will greatly affect the operation force and motor load, and it needs to be subjectively evaluated and reliability test needs to be implemented again, so this plan is not recommended.
5. Increasing the inertia moment of lock switching panel, can improve the endurance capacity of the lock mechanism to the frontal collision acceleration, and it has little influence on operation performance, so it is recommended to adopt this plan.

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