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Active-Steering-Embedded Execution Unit For Railway Vehicles

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Abstract

Active steering technology can effectively improve the curving performance of railway vehicles. The execution unit is an important part of the active steering system; it is used to implement the active steering control. Therefore, this paper proposes a scheme for designing an active steering embedded execution unit in railway vehicles that is based on flexible elastomers. This technique can be used to perform active steering control actuation, while also allowing the device to function as primary longitudinal suspension and fail-safe. The scheme adopts a working principle, which is significantly different from that of the conventional actuator, through the expansion or compression deformation of the rubber–metal mesh composite rubber bladder. The stiffness and displacement actuating capacity are realized by the expansion or compression deformation of the rubber bladder, thereby greatly improving the structural integration of existing technical solutions. To clarify the working performance of the primary longitudinal suspension and displacement actuation of the proposed unit, the stiffness, volume, and pressure characteristics of the core functional components (rubber bladder) of the scheme were analysed by establishing a finite element model. The calculation results show that in the passive state, the execution unit can provide primary longitudinal suspension stiffness between the wheel and bogie by using nonlinear characteristics. When the unit produces an active steering actuating displacement, the volume characteristics of the rubber bladder are similar to that of the conventional hydraulic cylinder, and the displacement control of the proposed unit can be implemented effectively by the conventional hydraulic servo-control system with a working pressure of not less than 16 MPa. The findings of this study can provide reference for the engineering application of the active steering system of railway vehicles.

Keywords: active steering, embedded execution unit, flexible-elastomer, rubber bladder, stiffness, volume, pressure.

1 Introduction

Active steering technology is an effective way to further improve the curve negotiating performance of railway vehicles [1,2]. The execution unit is an important part of the active steering system; it is used to implement the active steering control. To promote the further application and development of active steering technology, a new embedded execution unit based on flexible elastomer is proposed. The structure scheme of the execution unit is shown in Figure 1. As shown, the main structure of the unit can be embedded in the axle box, and the core functional component is the mandrel with a rubber–metal mesh composite rubber bladder on both sides. The rubber bladder and metal support are vulcanized as an integral structure and connected with the mandrel. The displacement sensor is arranged between the axle box and bogie to measure the actuating displacement, and the annular rubber stop is used for the fail-safe function.

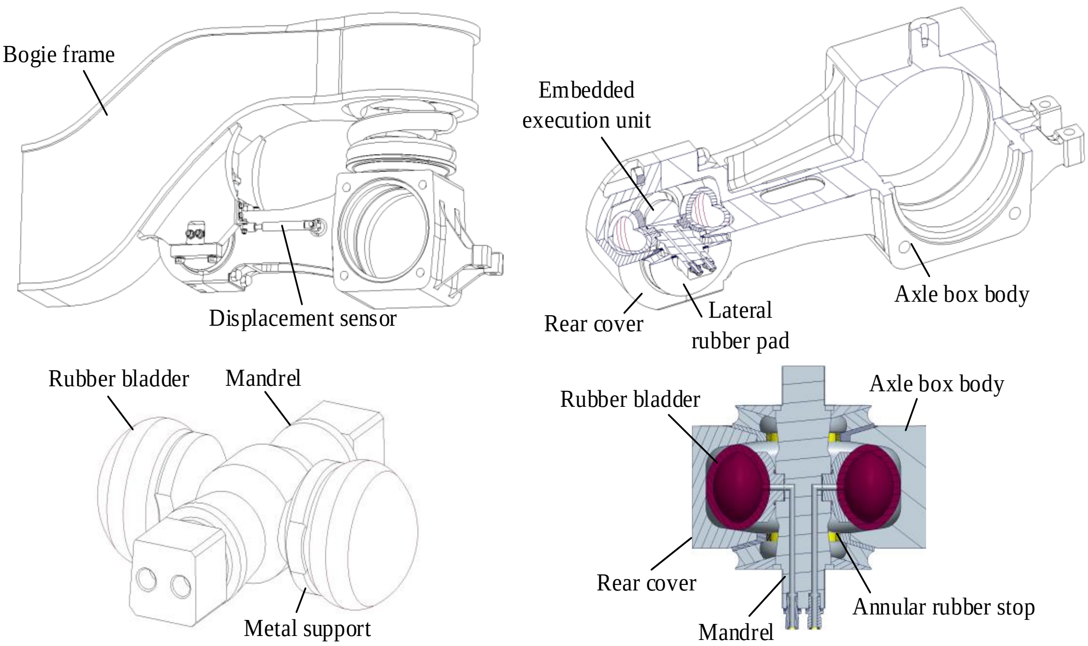

Figure 1: Structural scheme.

The working principle of the execution unit is shown in Figure 2. The primary longitudinal suspension stiffness between the wheel and bogie frame is induced by filling oil inside the rubber bladders on both sides of the mandrel and locking the oil chamber (passive state). Expansion deformation is induced by injecting oil into the one-sided rubber bladder, and the relative posture between the wheel and bogie can be adjusted until the whole wheelset is in the radial position (active steering state). When one side of the rubber bladder fails, the other side of the rubber bladder will actuate the axle box to move longitudinally relative to the bogie until the mandrel abuts against the annular rubber stop, and the wheelset is in a safe attitude [3] (failure state).

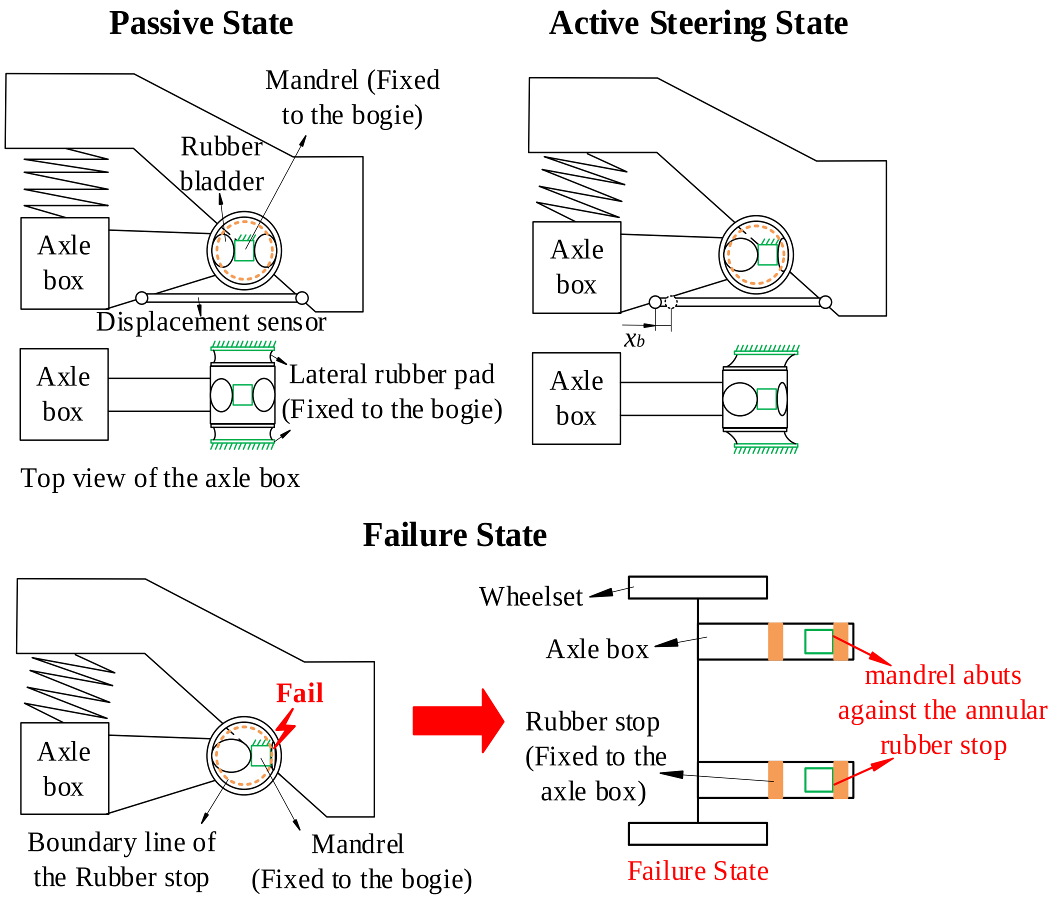

Figure 2: Working principle

The working principle of the proposed scheme is significantly different from that of the conventional actuator in that the stiffness and displacement actuating capacity are provided through the expansion or compression deformation of the rubber bladder. Compared with the existing engineering scheme of the active steering actuator [4,5], a considerable amount of space for installing the actuator on the bogie is saved and the integration degree is improved. To realize the further application of the above-mentioned scheme and clarify its basic working performance, its key physical properties such as stiffness, volume, and pressure characteristics, must be analysed.

2 Methods

Table 1 and 2 list some key parameters of the scheme and the corresponding finite element calculation model, respectively. These parameters were used to establish the model shown in Figure 3. The figure shows that the unnecessary geometric shapes of the mandrel and axle box of the conventional actuator are ignored and simplified to an axisymmetric structure to simplify the calculation process. In addition, the compressibility, viscosity, and damping parameters of the liquid and rubber materials are ignored. The key constraints and contact relationships between the rubber bladder and inner surface of metal components are retained in the modified model.

Property	Value
Structure size of the rubber bladder	77.5 × 80 × 80 mm
Thickness of the rubber bladder	8 mm
Wire diameter of metal mesh	1.5 mm
Wire spacing of metal mesh	
Wire angle of metal mesh	±25°
Rubber type	NBR
Material of wire	High-tensile steel wires

Table 1: Key parameters of the execution unit.

Property		Value
Elastic modulus of metal material		210 GPa
Poisson's ratio of metal material		0.3
Parameters of Mooney–Rivlin model	C_{10}	0.4825
	C_{01}	0.1206
Type of finite element unit	metal components	C3D8R
	metal mesh	SFM3D4R
	rubber bladder	C3D8RH
Finite element unit size	metal components	1–6 mm
	rubber bladder	0.7–4 mm
The total degrees of freedom for the model		220821

Table 2: Key parameters of finite element model.

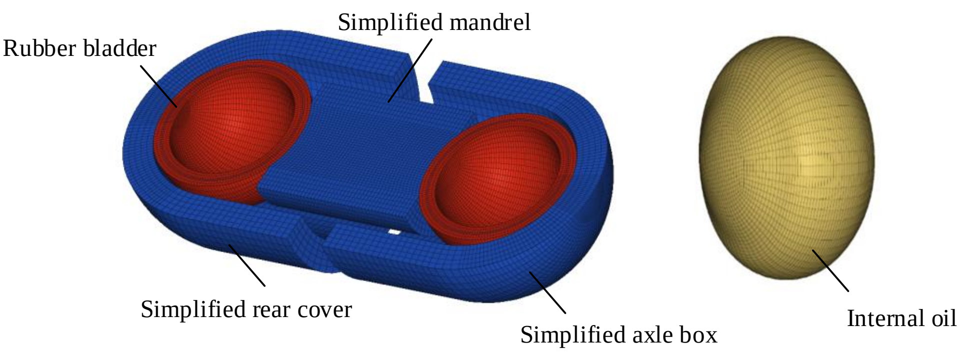

Figure 3: Finite element model (section view).

Figure 4 shows the calculation procedure of the different physical characteristics of the finite element model, as described below:

Apply the external load, F_b, to the end of the simplified axle box model, and calculate deflection x_p in the axial direction. The relationship between F_b and x_p is defined as the stiffness characteristic of the proposed unit and reflects the unit's ability to provide primary longitudinal suspension stiffness.

Next, generate expansion and deformation using the rubber bladder, and calculate the actuating displacement, x_a, under different loads F_b and inner cavity volume V_b as well as the relationship between V_b, F_b, and x_a; this is defined as the volume characteristic.

Next, calculate the variation law of internal pressure P_b under different loads F_b and actuating displacements x_a; this is defined as the pressure characteristic.

Finally, calculate the stress of the metal mesh embedded in the rubber bladder under different internal pressures P_b; this reflects the pressure resistance of the structure.

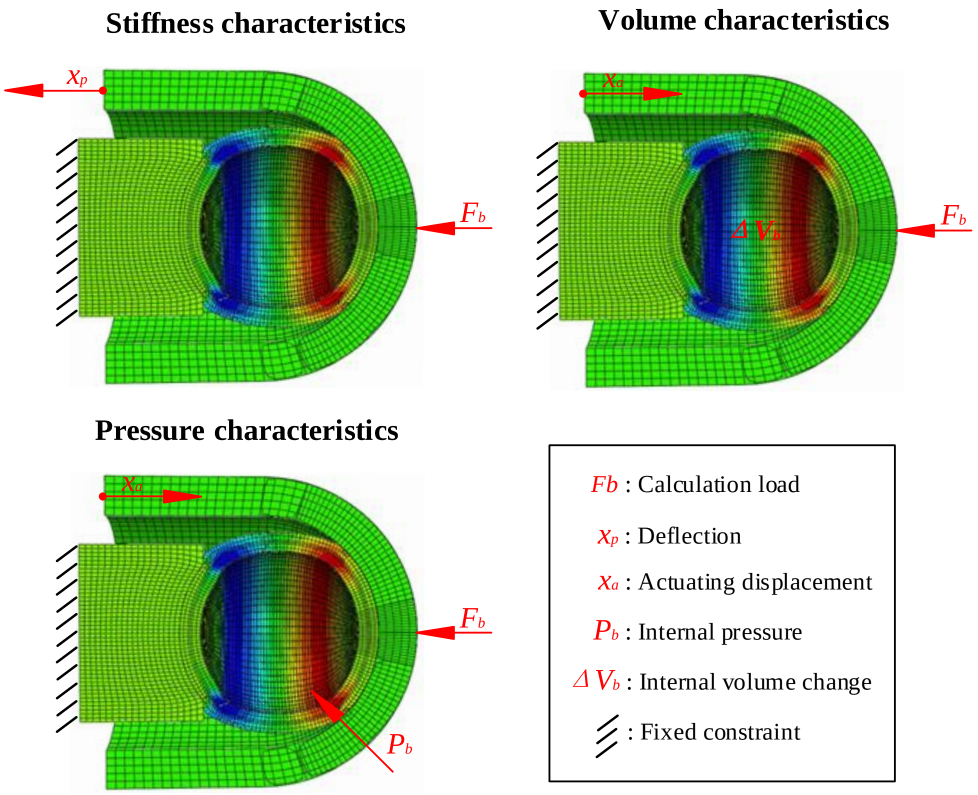

Figure 4: Calculation conditions.

3 Results

According to the results of the finite element calculation, the stiffness characteristics of the executive unit can be fitted to the curve shown in Fig. 5. The figure shows that when the axial load reaches $F_b = 30$ kN, the corresponding deflection is only 1.5 mm, indicating that the execution unit has a certain bearing capacity in this direction; its corresponding stiffness shows typical nonlinear characteristics.

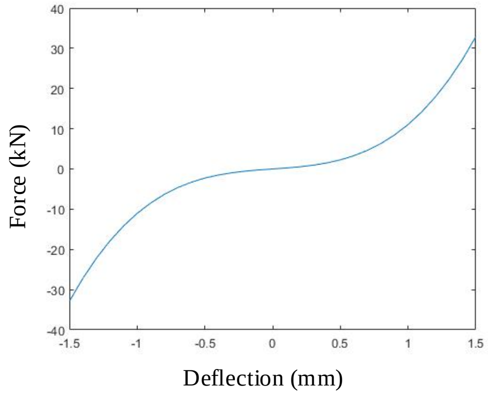

Figure 5: Stiffness characteristic curve of the executive unit.

The volume characteristics of the execution unit can be fitted to equation (1):

$$V_b = 0.0022x_a + 0.000128 \tag{1}$$

where V_b (m^3) is the volume of the inner cavity of the rubber bladder and x_a (mm) is the axial actuating displacement. The equation shows that when the rubber bladder generates actuating displacement through expansion and deformation under different external loads, a linear relationship is observed between V_b (m^3) and x_a (mm), which is almost independent of the external load. This law is consistent with that of the conventional hydraulic cylinder.

The variation law of internal pressure of the rubber bladder with actuating displacement x_a and external load F_b can be fitted according to the curved surface shown in Fig. 6. The figure shows that under normal operation conditions, when the actuating displacement and external load reach their maximum simultaneously (x_a = 5.5 mm, F_b = 30 kN), the internal pressure reaches its maximum, i.e., ~16 MPa. In this process, the peak stress of the metal mesh layer in the rubber bladder is ~275 MPa, which is far lower than the yield strength of the material (1170 MPa), indicating that the pressure resistance of the structure can fully meet the usage requirements.

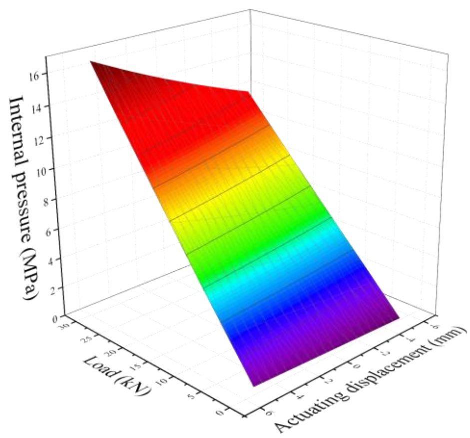

Figure 6: Pressure characteristic surface of the execution unit.

4 Conclusions and Contributions

To promote the further development and application of the active steering technology of railway vehicles, we propose a scheme to design an embedded execution unit based on flexible elastomers. This scheme significantly improves the integration and compactness of the existing solutions. A rubber–metal mesh composite bladder was used to provide the longitudinal suspension stiffness between the wheel and bogie and to perform the active steering control. In addition, the proposed scheme has a fail-safe function.

To clarify the basic working performance of the embedded execution unit, a series of key physical characteristics of its core functional components (rubber bladder), such as stiffness, volume, and pressure characteristics, were analysed using the finite element calculation method. The calculation results show that when the execution unit is in the passive state, it can provide the primary longitudinal suspension stiffness between the wheel and bogie with obvious non-linearities. In contrast, when the execution unit is in the active steering state, the relative longitudinal displacement between the wheel and bogie is adjusted according to the expansion deformation of the flexible elastic rubber bladder, adjusting the attitude of the wheelset relative to the bogie frame until the wheelset is in the radial position. In this process, the volume characteristics of the execution unit are almost the same as those of conventional hydraulic cylinders. Furthermore, the internal pressure of the rubber bladder can reach up to 16 MPa, and its pressure resistance can fully meet the usage requirements. Therefore, the effective displacement servo-control of the execution unit can be realized by the conventional hydraulic servo-control system with a working pressure no less than 16 MPa. To further verify the performance of the proposed scheme, some verification tests will be carried out as an important part of future work.

The results of this study can provide reference for the engineering application of the active steering system of railway vehicles.

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References

[1] Perez J, Busturia J M, Goodall R M. Control strategies for active steering of bogie-based railway vehicles [J]. Control Engineering Practice, 2002, 10(9): 1005-1012.

[2] Mei T X, Goodall R M. Recent development in active steering of railway vehicles [J]. Vehicle System Dynamics, 2003, 39(6): 415-436.

[3] Luo XP, Xiao CY. One Fault-oriented safety Policy of active radial system for urban rail transit vehicle. Urban Mass Transit. 2018;21(09):87–90

[4] Tian S, Luo X, Ren L, Xiao C. Active radial system of railway vehicles based on secondary suspension rotation angle sensing [J]. Vehicle System Dynamics, 2020, 1-20.
[5] Park J H , Koh H I , Hur H M , et al. Design and analysis of an active steering bogie for urban trains[J]. Journal of Mechanical Science & Technology, 2010, 24(6):1353-1362.