The Modelling of Middle Locomotives and Their Couplers of Heavy Haul Train and Dynamical Simulations under Pressing Coupler Force

Bin Li¹, Xi-hong JIN²,³, Yong-qiang HE²,³, Xing XIE²,³ and Wei-hua MA¹,*

¹Traction Power State Key Laboratory, Southwest Jiaotong University, 610036 Chengdu, China
²The State Key Laboratory of Heavy Duty AC Drive Electric Locomotive Systems Integration, 412001 Zhuzhou, China
³R&D Center, CRRC Zhuzhou Locomotive Co., Ltd., 412001 Zhuzhou, China

*Corresponding author

Keywords: LTD modelling, MBS modelling, Heavy haul train, Locomotive, Coupler system.

Abstract. To study the dynamic performance of middle locomotives and their couplers of 20,000t heavy haul combined train under pressing coupler force, the longitudinal dynamic characteristics of train’s electric braking, cyclic braking and emergency braking on straight track were calculated with the longitudinal train dynamics (LTD) simulation package TDEAS, the coupler force of middle locomotives were obtained and sent to multi-body system (MBS) model of train established in package SIMPACK, and then the dynamic behaviour of middle locomotives and their couplers under pressing coupler force were studied. The results show that under the pressing force in straight track, the vertical dynamic performance of locomotive will be influenced in certain degree, the guiding wheelsets will upload while the rear wheelsets unload, the more the pressing force is, the greater the upload and unload will be. There is less influence on lateral dynamic under straight track condition.

Introduction

The 20,000t heavy haul combined train is a common train formation in heavy haul transportation in China. For these trains, the longitudinal impulse often occurs in the middle of train, so the operation condition of middle locomotive is worse. When the length of train is larger, the larger pressing force of coupler will be due to the delay of brake transmission. Junjie Yang et al [1] established the 20,000t heavy haul train model in SIMPACK package, then simulated the pressed coupler by applying the negative acceleration, and calculated the maximum coupler angle under straight track. Zhichao Zhang et al [2] introduced contact friction process between arc surfaces of coupler-tail and following plate into the flattened knuckle pivot pin coupler, and researched on the influence of friction between coupler-tail and following plate as well as the arc radius of their surfaces on compressive stability of coupler system. Qiying Xu et al [3] established the coupler system dynamic models of type 13A/QKX-100 and type DFC-E100, and carried out simulations on coupler angling behaviours when locomotives negotiating curves. Gaofeng Chu et al [4] investigated the influence of the key second suspension parameters of locomotives on its running safety and coupler rotation angle. Xihong Jin et al [5] studied the adaptability of different kinds of coupler and draft gear through the aspects of free swing angle and stabilizing structure of coupler, character of draft gear, and suspension of locomotive. Xiaoming Yan et al [6] researched the safety of locomotive during brake cases.

This paper establishes the LTD model of 20,000t heavy haul combined train, obtains the coupler forces of the middle locomotives and wagons under different operations, then transforms them into force elements and sends them to the MBS model of train in SIMPACK package, and finally obtains the dynamic behaviour of middle locomotives and their couplers, thus the calculation of locomotives and their couplers’ running performance under the dynamical coupler force can be realized.
Simulations of Models

Longitudinal Dynamics of Train Model

The 1+1 type combined train with the configuration of 1 multi-locomotive + 105 wagons + 1 multi-locomotive + 105 wagons is modeled, every three wagons are treated as a unit, the traction bar with less coupler slack is used in the wagon unit, the coupler with coupler slack of 10mm is used among the wagon units. The buffer type of locomotive is QKX100, the buffer type of wagon is MT-2. The influences of traction force, brake force and resistance force are considered in the longitudinal train dynamics model, Fig.1 shows a common longitudinal train dynamics force analysis model.

Multi-body System Dynamics of Train Model

The MBS model of middle locomotive is established to analyse the operating behaviour, bodies such as the wheelsets, motors and their hangers, bogie frames and carbody are considered.

The heavy haul train is usually large, some simplification must be adopted to reduce calculation cost. The wagons behind middle locomotives are compressed into a single wagon with a longitudinal degree of freedom according to the mass, and connected with middle locomotives by coupler system.

The modelling of coupler system includes coupler and buffer. The coupler system includes coupler, follower plate, coupler yoke and buffer, in modelling of coupler system, the follower plate and coupler yoke can be considered as a whole body, which has a longitudinal degree of freedom relative to carbody, the buffer works between carbody and follower plate, the coupler has lateral and vertical degrees of freedom relative to the follower plate. The friction characteristic of coupler tail and stopping characteristic coupler shoulder shown in Fig.2 are considered at the same time. The factors such as upload and unload characteristics, coupler slack, initial force rigid impact and hysteresis are considered in the modeling of buffer. The dynamic model of coupler system is shown in Fig.3.

The locomotives, coupler system and wagon are assembled into the simplified train model with the configuration of locomotive A + locomotive B + wagon. The locomotive A and locomotive B
(simplified as Loco A and Loco B below) are referred to the former and latter locomotives respectively, the operating behaviour of 1st and 4th wheelsets (simplified as wst1 and wst4 below) of locomotives are measured. The coupler system between Loco A and Loco B is marked as coupler 1, corresponding to the 108th coupler system in the train, the coupler system between Loco B and wagon is marked as coupler 2, corresponding to the 109th coupler system in the train, as shown in Fig.4.

Simulations

Electric Braking

The LTD simulation results of electric braking are shown in Fig.5, the initial speed is 80km/h, the brake force of locomotives increase and reach the maximum at 20th second. It can be seen from time domain figure of 107th coupler’ force that when the brake forces reach the maximum the coupler’s pressing force begins to increases rapidly and then decreases after increasing to the maximum value of 218 kN. Please note that all the values of pressing coupler forces in this paper are negative.

Figure 5. The LTD simulation result of electric braking in straight track.

Figure 6. The operation behaviour of middle locomotives.

Figure 7. The operation behaviour of middle locomotives’ couplers.

Fig.6 (a) shows the lateral force of wheelset, the values are within the scope of 13kN and below the limit. Fig.6 (b) shows the unloading rate of left wheel, in electric braking condition, the guiding wheelsets, i.e. the 1st wheelsets of Loco A and Loco B, have uploaded during the simulation process,
the 4th wheelsets of Loco A and Loco B have unloaded during simulation process, and the uploading and unloading of Loco A are more obvious. When couplers’ pressing force reaches the maximum, so the phenomenon of uploading and unloading will be, the maximum unloading rate is 0.2 and below the limit. Fig.6 (c) shows the derailment coefficients of left wheels, which are below the limit.

Fig.7 (a) shows the coupler forces of middle locomotives, the couplers are pressed during the simulation process, the pressing force reach the maximum at 28th second, the maximum force for coupler 1 and coupler 2 are 448kN and 674kN respectively. Fig.7 (b) shows the coupler angles of middle locomotives, the angles are relatively small because of the straight track condition, which are within the scope of 0.6°. Fig.7 (c) shows the lateral component of coupler forces of middle locomotives, which are within the scope of 10kN, the value of coupler 2 is relatively large.

**Cyclic Braking in 12% Long and Steep Down Grade Condition**

![Figure 8](image)

Figure 8. The LTD simulation result of cyclic braking in 12% long and steep down grade condition.

The LTD simulation results of cyclic braking in 12% long and steep down grade are shown in Fig.8, the initial speed is 60km/h and 80% electric brake force of locomotives are applied. When train’s speed reaches 75km/h, the train starts braking and pressure of train pipe is reduced by 50kPa, when train’s speed reduces to 55km/h, the train starts relieving. Fig.8 (a) shows train’s speed, there are two cycles in simulation and last 440 seconds. Fig.8 (b) shows locomotives’ electric brake force and wagons’ brake force, it can be seen that when train’s speed increases to 75km/h at 65th second, the pressure of train pipe starts reducing, the wagons’ braking force reach to 14.1kN in 27 seconds, then increases slowly until 169th second, when train’s speed reduces to 55km/h, then the train starts relieving and wagons’ braking forces start reducing. The train speed increases to 75km/h again at 280th second, and previous behaviour will be repeated. Please note that the electric brake force of locomotives reduces slightly when train pipe starts reducing. Fig.8 (c) shows the coupler force of 107th coupler, when electric brake forces reach 80%, the pressing force of coupler increases rapidly, then reduces after reaching maximum pressing force valuing 210kN. The coupler starts pulling at 169th seconds, when train starts relieving, the pulling force of coupler increases and reaches maximum when brake force of wagons disappears, then the pulling force of coupler starts reducing.

![Figure 9](image)

Figure 9. The operation behaviour of middle locomotives.

Fig.9 (a) shows the lateral force of wheelsets, the values are within the scope of 13kN, which are below the limit. Fig.9 (b) shows the unloading rate of left wheel, in the cycling braking condition, the
guiding wheelsets, i.e. the 1st wheelsets of Loco A and Loco B, have uploaded during the simulation process, the 4th wheelsets of Loco A and Loco B have unloaded during the simulation process, and the uploading and unloading of Loco A are more obvious, under the increasing coupler pressing force, the phenomenon of uploading and unloading will sharpen, when the coupler pressing force reduces, the guiding wheelsets unload while rear wheelsets upload. Fig.9 (c) shows the derailment coefficients of left wheels, which are below the limit. Please note that the MBS simulation only selects a cycle.

Fig.10 (a) shows the coupler forces of middle locomotives, couplers are mainly pressed during simulation, the pressing forces increase and reach the maximum at 27th second, the maximum force for coupler 1 and coupler 2 are 397kN and 579kN respectively. Then the pressing forces reduce, the pressing force reduce to minimum values when the brake forces of wagons disappear. The trends of coupler 1 and coupler 2 are in accordance with the 107th coupler. Fig.10 (b) shows the coupler angles of middle locomotives, the angles are relatively small because of the straight track condition, which are within the scope of 1.0°. The angle of coupler 1 will oscillate at beginning and the time when the wagons’ brake force disappears. Fig.10 (c) shows the lateral component of coupler forces of middle locomotives, which are within the scope of 10kN, the value of coupler 2 is relatively larger.

Emergency Braking

The LTD simulation results of emergency braking are shown in Fig.11, the initial speed is 80km/h. The braking is applied at beginning, the simulation lasts 46 seconds. Fig.11 (b) shows locomotives’ brake forces and wagons’ brake forces, the locomotive brake cylinders’ pressures increase rapidly and reach maximum fastly. Locomotives’ brake forces start increasing at 5th second, then increase slowly after reaching 260kN, finally reach 343kN in the end. From the brake forces of 110th, 120th,.., 210th wagons, the brake forces of wagons start increasing at 5th second, then increase slowly after reaching 47kN, finally reach 61.7kN at the end of simulation. Fig.11 (c) shows the force of 107th coupler, the maximum value occurs at the 13th second, and the maximum value is 913kN.

Figure 10. The operation behaviour of middle locomotives’ couplers.

Figure 11. The LTD simulation result of emergency braking in straight track condition.
Figure 12. The operation behaviour of middle locomotives.

Fig.12 (a) shows the lateral force of wheelsets, the values are within the scope of 10kN, which are below the limit. Fig.12 (b) shows unloading rate of left wheel, in the emergency braking condition, the guiding wheelsets, i.e. the 1st wheelsets of Loco A and Loco B, have uploaded during the simulation process, the 4th wheelsets of Loco A and Loco B have unloaded during the simulation process, and the uploading and unloading of Loco A are more obvious, the unloading rate of 4th wheelset’s left wheel approaches the limit, but the vertical force of 1st wheelset’s left wheel is below the limit. Fig.12 (c) shows the derailment coefficients of left wheels, which are below the limit.

Figure 13. The operation behaviour of middle locomotives’ couplers.

Fig.13 (a) shows the coupler forces of middle locomotives, the couplers are pressed during the simulation process, the pressing forces increase rapidly at 10th second and reach the maximum at 12th second, the maximum force for coupler 1 and coupler 2 are 1178kN and 1449kN respectively. Fig.13 (b) shows the coupler angles of middle locomotives, the angles are relatively small because of the straight track condition, which are within the scope of 0.6°. Fig.13 (c) shows the lateral component of coupler forces of middle locomotives, which are within the scope of 7kN.

Summary

In braking condition, the coupler systems of middle locomotives are mainly pressed, and the pressing force of coupler between middle locomotive and wagon is relatively larger. The greater the braking force is, the larger the pressing force will be. Due to coupler’s well compressive stability, there is no large angle of coupler under braking condition in straight track, the lateral component of coupler forces and lateral dynamic performance of the locomotive are relatively small.

Under the pressing force, the vertical dynamic performance of locomotive will be influenced in certain degree. Especially the unloading rate of left wheel, but all results are below the limit.

Acknowledgement

This paper is supported by the National Natural Science Foundation of China (No 51575458).
References


