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Mechanism Research of Train Longitudinal Inpulsion Based on the Brake Emulation of High-speed Freight Train

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Abstract: Longitudinal dynamic analysis for 20-groupage, 18t-axle-load high-speed wagons under the operation of service braking and emergency braking were investigated using longitudinal dynamics analysis system, which was based on air brake system emulation. According to the simulation results, the longitudinal impulsion was differentiated into two parts, which were Aextrusion coupler force@ and Aimpact coupler force@. Some advises were also put forward to reduce the longitudinal impulsion.

Key words: Railway, high-speed train, brake emulation, impact coupler force, pressing coupler force

INTRODUCTION

High speed and heavy load railway transportation in China is an effective means to improve the transport capacity in recent years. With the increasing of train speed, the train longitudinal impulse will become more obvious, especially when train = s braking. It will cause severe longitudinal impact, produce large coupler force, which will cause the severe wear of the components, cargo damage, coupler fracture, even derailment accident. Therefore, to study the train longitudinal dynamics, make clear of the train longitudinal impulse mechanism, so as to avoid the adverse factors to lead to strong longitudinal impulse, is greatly used of the maintenance of high speed and heavy haul transportation sustainable development.

Longitudinal dynamics research is developed along with the development of railway transportation especially the heavy haul transportation as well as the computer technology. This research method can greatly reduce the economic cost for test study and avoid the adverse effects of the experimental data error. At the same time, it ensure greatly shorten the research cycle under certain accuracy premise. Brake = s not synchronization is the leading cause of train longitudinal impulse, therefore, Europe, the United States and Australia railway first carried out the research of the train dynamics simulation. The research was mainly in braking pipeline gas flow simulation (Hiroshi and Izumi, 1986; Izumi *et al*., 1987; Tadeusz, 2009, 2010), braking system simulation (Seong and Hyeong, 2002; Pugi *et al*., 2007, 2008) and forecast of the braking characteristics of several aspects (Abdol-Hamid *et al*., 1986; Cantone *et al*., 2009, 2011). In China, Academy of Railway Sciences and Southwest Jiaotong University has developed the longitudinal dynamics (Hong and Ma, 1989; Sun *et al*., 1986) early. In their studies, it often use braking characteristics test curve combined with hypothesis mode to fit the air braking characteristics. Dalian Jiaotong University = s air braking simulation of train longitudinal dynamics study (Wei, 2006, 2007; Wei *et al*., 2012), avoided the hypothesis of braking characteristics. They successfully developed a 120 Valve and 104 valve simulation system and had applied to the research of heavy haul train longitudinal impulse successfully.

The longitudinal dynamics research mostly focuses on the heavy haul train = s longitudinal impulse. The high-speed freight car = s marshalling is short, so the longitudinal impulse problem is not up outstanding, so the relevant research is less. The most longitudinal dynamics research is the influence of brake = s asynchronous. Less study was about the coupler force of impulse and the analysis of the causes. This study based on the subject of high-speed freight car coupler and buffer technology manufacture and test research of Qigihar Rail Traffic Equipment Co Ltd. The air brake and train longitudinal dynamics simulation system is developed by own research group. Together, the quantitative analysis of the high speed vehicle in braking and emergency braking, the maximum coupler force and its distribution along the car and the time of occurrence was studied. The coupler force is divided into two different forms of "impact force" and "extrusion force". The research methods of this study provided useful ideas and methods for analyzing the longitudinal impulse of train

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braking mechanism. The conclusions are helpful for the reduction of the car coupler force and improvement suggestions.

MODEL

Car model: In this study, 20 cars, the 18t axle load, the running speed of 160 km h^{-1} high speed container flat car was taken as the research object. The longitudinal impulse level and characteristics was analyzed under the conditions of the service brake and emergency brake operating. The train is abstracted as a multi particle system of many mass, springs, damper system. Any vehicle loading is as shown in equation 1. In the left of the equation, there is inertial force and the coupler force, braking force, resistance is in the right. From the formula 1, calculating accurate depends on the actual situation of the coupler force, braking force and resistance. Resistance was obtained from procedures of "China's train traction". The coupler force and braking force will be introduced below:

$$m\ddot{x} = F_{coupler} + F_{braking} + F_{resistance} \tag{1}$$

Braking performance: The braking performance is an important factor to affect the accuracy of simulation results. In this study, braking characteristics was obtained by air braking simulation system developed by research group of Dalian Jiaotong University. After long time application, the accuracy of air braking simulation system has been recognized (Wei, 2006, 2007; Wei *et al*., 2012). The 20-car train model of this study is equipped with 104 air distribution valve. In the condition of initial pressure 600 kPa and the reduced pressure 170 kPa, the service brake characteristic of car located in the front, meddles and rear were simulated. The brake cylinder pressure curve and braking wave transfer characteristic curve simulation results were shown in Figure 1 and 2 respective.

When service braking, the increase speed of the brake cylinder located in different positions were different. The closer to the locomotive, the boost faster. The brake wave transfers not according to a certain velocity, but slow at first and fast in the after.

In emergency braking, brake cylinder pressure curve and braking wave transfer characteristic curve of the were shown in Fig. 3 and 4.

When emergency braking, the vehicle brake cylinder pressure curve is consistent basically at a constant speed, braking wave propagation at a same speed.

Coupler and draft gear performance: Buffer characteristics is also an important factor to affect the accuracy of simulation results. In this study, the

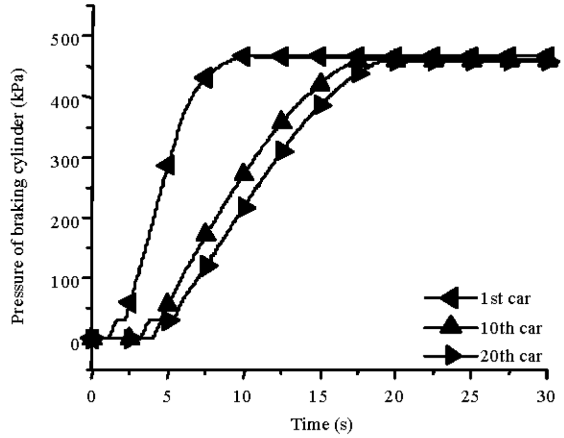

Fig. 1: Braking cylinder pressure of front, middle and rear car when service braking

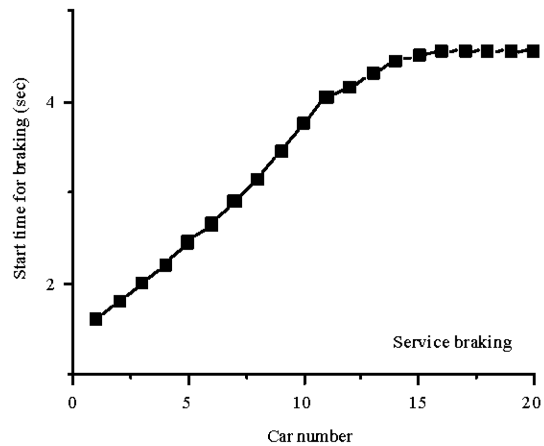

Fig. 2: Brake propagation speed when service braking

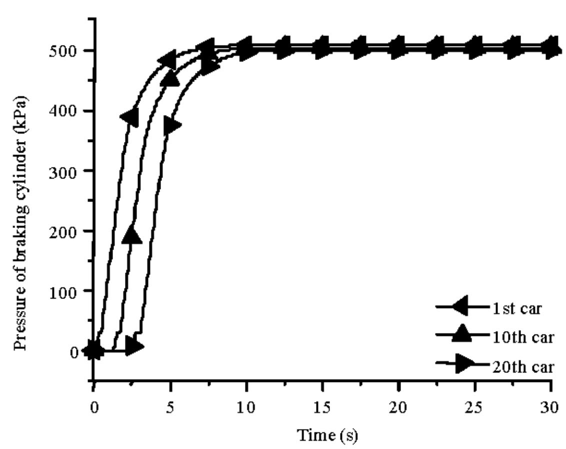

Fig. 3: Braking cylinder pressure of front, middle and rear car when emergency braking

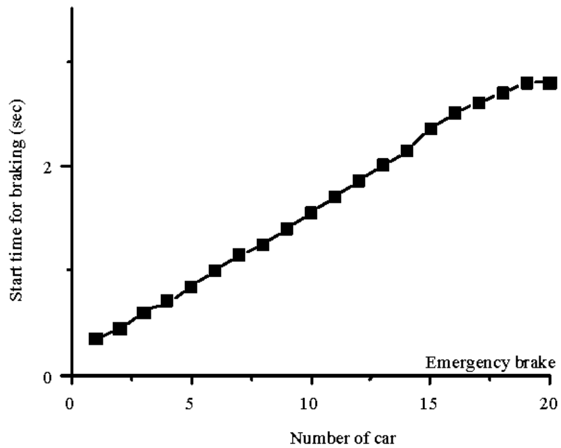

Fig. 4: Brake propagation speed when emergency braking

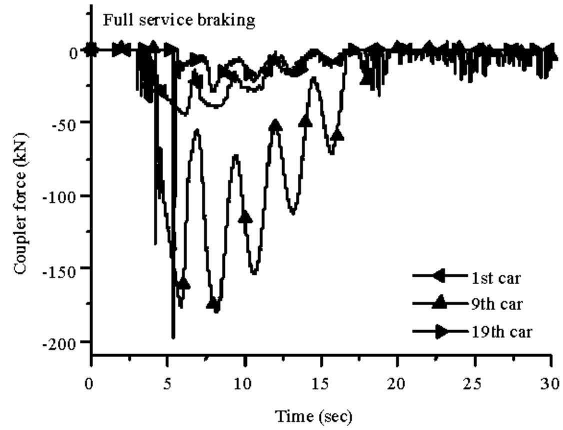

Fig. 5: Coupler force when service braking

mechanical model of HM-1 type buffer characteristics of high speed truck was abstracted as two parameter model of stiffness and damping. The two parameters mechanical model was as follows:

$$F = K\Delta X + C\Delta\dot{X} \quad (2)$$

The F was coupler force. The ΔX was the relative displacement between two adjacent vehicles. The $\Delta\dot{X}$ was the relative velocity between two adjacent vehicles. K, C are the stiffness and damping of the buffer. According to the single collision test results of Qigihar factory, the K and C parameters in the buffer was determined. The 13B type coupler was used in the train and the coupler gap was 10.5 mm.

SIMULATION RESULTS

The coupler force with time, the maximum coupler force along the car distribution and the moment of maximum compression coupler force curve of the first, middle and rear car were shown in Fig. 5-7 in the condition of service brake in straight lines.

From Fig. 5, we can see that there are always compression force during braking process in every coupler and there are almost no tensile force. Three different characteristics of the coupler force can be recognized from the figure. The front vehicle, similar to the first car, which forces characteristics is the first kind. Because no limiting cars ahead and the behind vehicle was restriction by the following vehicle, so the impact and extrusion phenomenon is not obvious. Therefore, the vehicle coupler pressing force is small. The middle cars like ninth car were the second kinds. In the front of the

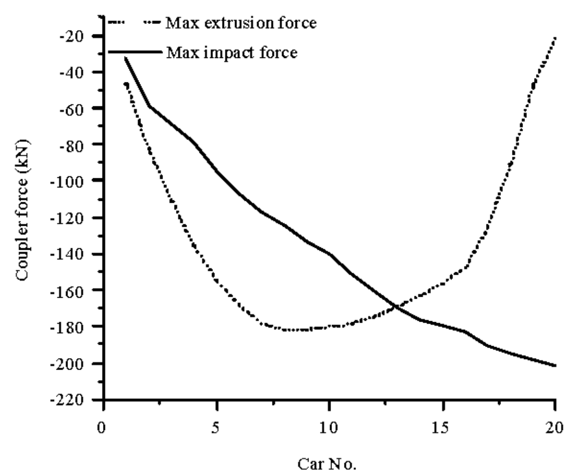

Fig. 6: Maximum impact force and extrusion force distribution

car, there is a front vehicle to intercept and behind the car, there is rear vehicle rushed, so after the gap finished, There occurred a sharp force, we called it impact force, then produced many wide compression coupler force, which we called it extrusion force. One of the biggest coupler force produced in the second extrusion cycle. The third types occur in the rear of the train just like the 20th car, in front of which, there was intercept by the former central vehicle and in the behind, there is no any restrict. Therefore, in the first significant coupler force, then no more significant peak occurred. Each coupler force present periodic change with time and the cycle was about 3-4s.

We find out the impact force peak and extrusion peak from every car, drawn it in Fig. 6. The impact force

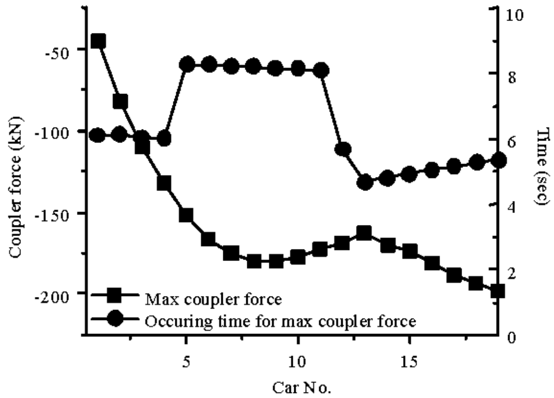

Fig. 7: Occurring time for maximum coupler force

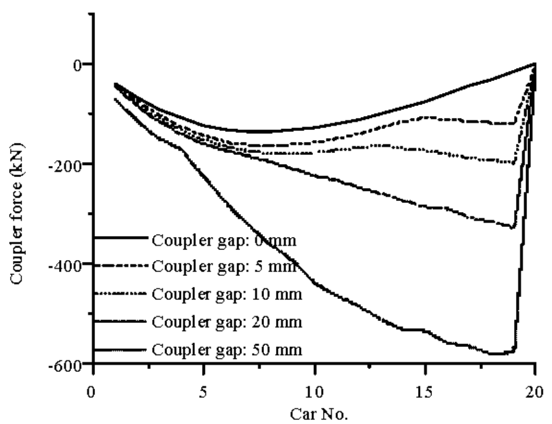

Fig. 8: Effect of coupler gap for maximum force

increases gradually along the vehicle from front to rear, the extrusion force increase from front to middle, then decreased from middle to rear. The maximum coupler force appears in the rear of the train, the value is 198.1kN, caused by the impact when vehicle's braking.

The occurrence time of maximum coupler force and the force value were shown in Fig. 7. The total maximum coupler force along the length distribution was the bigger of the maximum impact force and the maximum extrusion pressure. Therefore, the maximum coupler force along the length distributions are presented for the two curves. Form this calculation results, the maximum coupler force of the whole train is at end of train, was caused by impact.

In Fig. 8, there is an analysis of the coupler gap from 0mm gradually increased to 50mm, the maximum impact force, the maximum extrusion coupler value. When the coupler gap is 5mm, the total maximum coupler force appears inflection point in the fifteenth car. Before fifteenth car, the maximum coupler force composed of impact force and the car after the fifteenth car, the maximum coupler force was extrusion pressure. When coupler gap is 10 mm, the maximum impact car coupler force and maximum extrusion coupler force equal in the thirteenth car. When the coupler gap was 20 mm, the maximum impact and maximum compression coupler force are in the seventh car. When the coupler gap was up to 50 mm, the equilibrium point forward to fourth car. In the condition of the coupler gap is 10 mm, the maximum impact force and the maximum extrusion coupler force was comparative. When coupler gap continues to decrease, the total maximum coupler force was produced by extrusion maximum coupler force in the middle of the train. In the constitutes the whole train coupler gap is 0, in this extreme conditions, the train had no impact coupler force generation. When the coupler gap increases, the last vehicle impact coupler force constitutes the maximum coupler force of the full train.

The distribution of two kinds coupler force along the car of first, middle and the tail car when the emergency brake were shown in Fig. 9-10.

As seen in Fig. 9, compared with the service braking, emergency braking is still not synchronous. The vehicle between the coupler suffered a great impact, the coupler compression force is larger. While the tensile coupler force is not obvious, this is the same with service brake. Compared with the service brake, the brake synchrony increased, the vehicles no longer produce multiple wide extrusion peaks, but only one. The cycle time and braking of multi peak is basically the same, are 3-4s. In front of the extrusion peak, there is still a slightly sharp peak. The maximum compression coupler force occurred in twelfth car, caused by the extrusion, the value is 355.1kN, 44.2% larger than the service braking. The occurring time is 3.12s, which is earlier than the service brake.

Because the braking action of the emergency brake is faster, more quickly than service braking, the individual vehicle extrusion and impact features are hard to distinguish, the obviously distinguish extrusion and impact characteristics of vehicle were plotted in figure 10. The envelope maximum coupler force formed by extrusion and maximum impact coupler force was the total maximum coupler force along the length when emergency braking. The maximum force of front vehicles was induced by extrusion. The twelfth vehicle coupler forces was the maximum, compared with service brake, it move back 3 spaces. The maximum force of the rear vehicle is impact. The maximum impact occurs in the last part of the vehicle, the value for the 338.0kN. It is 4.8% smaller the the extrusion.

The maximum coupler force and the time of service braking and emergency braking are shown in Table 1.

Table 1: Occurring time and position of max coupler force

	Max coupler force (kN)	Occurring time (sec)	Position
Service braking	-198.1	5.37	19
Emergency braking	-355.1	3.12	12

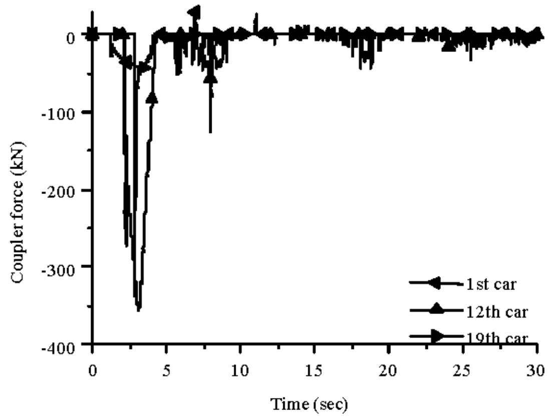

Fig. 9: Coupler force when emergency braking

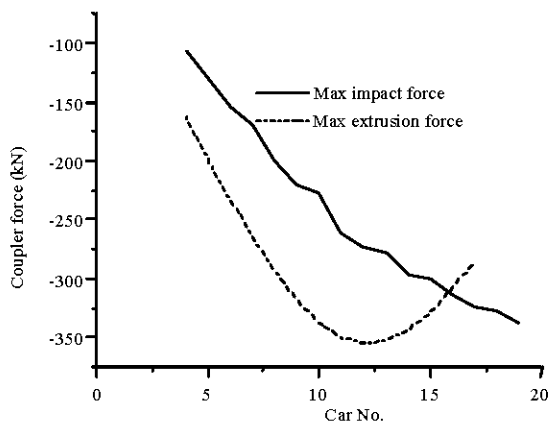

Fig. 10: Maximum impact force and extrusion force distribution when emergency braking

CONCLUSION

The 104 valve air braking system and HM-1 coupler buffer system may satisfy the 160km/h speed freight train. For the 20 car train, when service braking, the compression coupler force is 198.1kN, appearing at the end of a coupler, caused by impact. When emergency braking, the compression coupler force is 355.1kN, appearing in the middle position of the train, caused by extrusion. From the results of the coupler force simulation, we can see whether the service braking or emergency braking, high-speed freight car coupler force amplitude is far less than the heavy train.

Through the analysis of the coupler force of service braking and emergency braking, we can make conclusion that coupler force can be divided into "impact coupler force" and "extrusion coupler force". When train braking, first, the rear vehicle going through the coupler gap and impact the front vehicle. Then, the rear vehicle extruded the front vehicle and produce one or more longer duration. For the whole train, impact force along the length increases and the maximum extrusion pressure is occurred in the middle.

The maximum coupler force is closely related to the coupler gap. When the coupler gap shrinks, if the maximum coupler force is still the impact, the maximum coupler force may be reduced. If the maximum coupler force generated by the impact, the maximum coupler force will going forward, to train middle. With the increase of coupling gap, the maximum impact coupler force increases significantly higher than the maximum extrusion coupler force. The maximum coupler force produced by extrusion is related to the brake synchrony and reduction speed of train pipe pressure. in general, in the emergency brake, coupler force was much higher than that of service braking.

DISCUSSION

For high-speed freight trains, the requirements of high-speed make the train should not be too long, so when braking, the longitudinal impulse process is not too complex. High speed freight train longitudinal dynamics analysis model is simple, conclusions are clear and easy to found coupler force law. Through the study of simple vehicle longitudinal dynamics model , the mechanism of braking mode, coupler gap on extrusion coupler force and impact, would also make use to longitudinal dynamics analysis of heavy haul train. High speed freight transport is often service the timeliness requirements of high value-added goods, how to improve the stability of the truck running at a high speed, to ensure the safe transportation of goods is more highlighted the need to consider the problem.

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