Dynamics Characteristic Analysis of Coupler and Buffer System of Heavy Haul Train

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Abstract: Aiming at the safety problem of the locomotive under the dynamic braking condition, the influence of the coupler and buffer system on the dynamic performance of the locomotive has been researched by dynamic simulation. It compares the coupler reposition methods of the large rotation angle coupler and the small rotation angle coupler under longitudinal coupler press force. Results show that the longitudinal coupler press force afforded by large rotation angle coupler with coupler shoulder is larger than that of small rotation angle coupler. Due to its smaller static impedance, large capacity elastic clay buffer can’t satisfy the requirement of the heavy haul locomotive during the cycle brake case in the long heavy down grade, and the use of friction clay buffer can solve this problem.

Keywords: Coupler and buffer; Longitudinal; Heavy haul; Dynamics; Wheel/rail.

Introduction

During the development of heavy haul train, there are lots of problems about coupler and buffer system, such as decoupling, breakage of coupler, fracture of draft yoke pin, fatigue damage of the coupler, breakage of the buffer, etc. Relevant departments have taken a lot of researches on it, and made amount of improvement in coupler structure strength and manufacturing technology to solve these kinds of problems [1-4]. Researches of buffer are mainly concentrated on dynamic impedance characteristics of the buffer. Chang Chongyi, etc. have researched the property of heavy haul freight train buffer based on the response surface, and analyzed the relationship among the main parameters, resistance, and capacity of MT-2, as well as taken some researches on the effect of different properties of buffer under the longitudinal force of the trains [5-6]. Besides, there are some other references have taken research on the capacity of buffer and dynamic impedance characteristics [7-8].

The research on coupler and buffer mainly focuses on the structure strength, the buffer’s activity in absorbing capability, dynamic impedance characteristics, etc [1-8], and most of the dynamics analysis of heavy haul train focus on train’s longitudinal impulse and damping capacity, but rarely relate to the braking stability of coupler and the buffer’s static impedance characteristics [9-10]. However, American AAR has carried out the provisions about the braking safety problem of the heavy haul train in some aspects, such as coupler design standard, air-braking, and train maneuvering [11]. The mass of freight trains is limited within 2000/2400 tons by the European National Associations due to the safety issues arise when strong driving or braking forces are applied while the vehicle is running on sharp radius curves [12]. There are few researches concentrate on specific impact of coupler and buffer under longitudinal press force in and abroad [13].

The mass and length of the train have increased dramatically since the launch of 10000t class train. Coupler and buffer system have made to afford excessive impact force along with the improvement of running speed. The increase of train’s length will lead to lengthen the braking wave propagation time incredibly. As the existence of free rotation angle of coupler, the coupler and buffer system will deflect from the centre line when the coupler is suffering longitudinal press force, and then the car body will suffer a horizontal force at coupler position; if the coupler press force is large enough, it will lead to locomotive derailment accident [15-17]. Static impedance of the buffer also has greater influence, especially in cycle brake case on long heavy down grade.

Aiming at the phenomenon of locomotive derailment during dynamic braking and buffer damage problem of the train in Daqin line, it has researched the influence of the coupler and buffer system on the dynamic performance of the heavy haul locomotive.

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1 Coupler Stability Analyses
Besides connecting vehicles, transmitting traction and impact forces, couplers should have the freedom of rotation relative to the car body for the purpose of curve negotiating. The limit angle of couplers is determined by minimum radius of curve. When train pass curves with minimum radius, couplers can rotate freely. However, it doesn’t mean that the bigger the free angle of couplers is, the better it will work. Because the couplers are supposed to provide reposition force so that the free angle of couplers with a reasonable value is required.

As the existence of free rotation angle, couple rs are unstable under longitudinal press force. When coupler pivot pins of two connecting couplers are not in the center line of the train, a moment will created by the coupler force which makes couplers deviate the train center line more seriously. And it will go on until other accessories provide the supporting moment. The force between coupler heads of two connecting couplers can be ignored because it is just internal force in the coupler and buffer system.

Couplers can be classified into couplers with large rotation angle and couplers with small rotation angle, according to the matching method between the coupler and knuckle pivot pin. There are two different ways to provide the reposition moment by the coupler and buffer system for the two kinds of couplers; they are stop method and coupler shoulder method, which are corresponding of small and large rotation angle couplers, respectively. Some of the HeXie type locomotives are equipped with large rotation angle couplers with coupler shoulder, which has great ability of reposition and is widely used in American heavy haul train. Some HeXie locomotives are equipped with 13A type coupler called small rotation angle couples.

1.1 Stability style of large rotation angle couplers
Because both the knuckle pivot pin and coupler yoke pin of the couplers with large rotation angle have round shape, the rotation angle of the coupler can not be restrained. For the couplers with large rotation angle, the rotation angle which has coupler shoulder and automatic centering device is about $17^\circ$, while the other one without it gets a rotation angle of $38^\circ$. With regard to the large rotation angle coupler, coupler shoulder which will prevent the rotation angle increasing when the coupler reaches a certain place must be set.

Large rotation angle couplers with coupler shoulder are used in the HeXie locomotive. For these couplers, coupler shoulder in combination with car body stabilized coupler method is adopted. The principle of it is shown in Fig.1. If the coupler is loaded with $T_1$, the coupler shoulders can’t contact the coupler yoke first, and the force is totally loaded on the knuckle pivot pin. The coupler can’t keep in balance under the longitudinal press force, and coupler deviation will happen and increase until touching the coupler shoulder. A considerable part of the force is transferred to the coupler shoulder when coupler shoulders contact; $T_1$ becomes less, and the force $T_2$ on both front and back coupler forms a reposition moment which resists the coupler from deviating. The force $T_1$ on the front and back coupler pin forms an overturning moment until it is balanced by the reposition moment generated by the lateral force $F_C$ of car body, and the coupler keeps an appropriate and stable deviate state. Thus, overturning moment is $T_1 \times h_1$, and the reposition moment is $T_2 \times h_2 + F_C \times h_3$.

Fig.1   Reposition principle of large rotation angle coupler under the coupler force

1.2 Stability style of small rotation angle couplers
A coupler with small rotation angle is shown in Fig.2; long and flattened knuckle pivot pin cooperating with elliptical hole in the same shape is used in the coupler. One kind of typical small rotation angle coupler in China is No.13A type coupler. When loaded with coupler press force, the coupler rotates horizontally. The special shapes of the knuckle pivot pin and the coupler yoke pin act as stop setting, which can limit the horizontal rotation angle in certain scope. Therefore, it is called coupler with small rotation angle. Taking the 13A coupler as an example, its free rotation angle is about 9~11° at one side.

For the design of small rotation angle coupler, the stabilizing capability of the coupler is not concerned, and the reposition equipment is only used for the automatic replacement in marshalling without considering the automatic centering replacement when the coupler suffers the longitudinal coupler press force.
Besides the coupler and buffer system, the car body also has the coupler stabilizing capability. And the stabilizing capability of the car body plays an important role no matter the locomotive is with large or small rotation angle coupler. When the locomotive is running on a straight track, the bogie has the ability of automatic centering. When the coupler sustained the pressing force, the coupler deflection will occur and this will cause the lateral force apply on the car body at the coupler yoke pin position. It will be transferred to the bogie by the secondary suspension, causing the lateral deviation of the bogie and extra lateral wheel set force, which will resist the lateral movement of the car body and provide the supporting moment for coupler.

### 2 Analyses of Buffer Impedance Characteristics

#### 2.1 Static impedance characteristic

Static impedance characteristics have greater impact on buffer performance of the train during the cycle braking in long ramp grade track. If the static impedance force of buffer is less or close to the continuous traction force of the heavy haul train and the cycle braking force in long ramp grade track, the buffer stroke becomes larger. The remaining capacity of the buffer and the remaining stroke are too small to satisfy the requirement. Thus, it leads to buffer damage phenomenon.

Test results of Daqin line shows that the maximum coupler force of the 10000t train is about 900kN, the same result also appears on the 10000t train in Queensland, Australia and South Africa Spoornet through the dynamic simulation [9]. The maximum static impedance force of the buffer of HeXie locomotive: \( \geq 1200 \text{kN} \), capacity: \( \geq 35 \text{kJ} \), absorption rate: \( \geq 45\% \). Therefore, when the static press of the front coupler of the train is about 900kN, the remaining stroke is 1/4 less than the normal buffer travel stroke.

#### 2.2 Dynamic impedance characteristics

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<th>Dynamic impedance characteristics of buffer:</th>
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<tr>
<td>The maximum dynamic</td>
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<tr>
<td>Impedance force: ( \leq 2500 \text{kN} )</td>
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<tr>
<td>Capacity: ( \geq 100 \text{kJ} )</td>
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<tr>
<td>Absorption rate: ( \geq 80% )</td>
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<td>Initial pressure: ( \leq 150 \text{kN} )</td>
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<td>Stroke: ( \leq 83 \text{mm} )</td>
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**Fig.3** Dynamic impedance characteristics of large capacity buffer of HeXie locomotive

The maximum force which the buffer can support is generated when the buffer has maximum deformation, which corresponds to the greatest impedance; and its value should be adapted to the maximum allowable longitudinal force that the vehicle structures can support, to ensure buffer play a protective role for the vehicle and cargo. Larger dynamic impedance force and buffer stroke can increase the capacity of the buffer, and improve the buffer function and energy absorption rate. Buffer impedance characteristic curve has great influence on damping the longitudinal impact of the train. The character of the buffer of heavy haul locomotive of Daqin Line is shown in Fig.3.

### 3 Dynamics Models

#### 3.1 Train model

Train dynamics research mainly focuses on longitudinal dynamics, such as longitudinal impulse problems caused by train operation, braking and traction; and the train model is usually formed by the vehicle model with only one degree of freedom, and the vehicles are usually connected by simplified coupler model. There are rare researches on three dimensional vibration problems and can not fully reflect the real working state of locomotive and coupler and buffer system. The locomotive model, coupler and buffer model, simplified
truck model setup by utilizing the dynamic software, can reflect the real state of the locomotive
and the coupler system. HeXie locomotives which adopt 2B₀ axle type have two same bogies. The bogie is mainly
made up of attachments, wheel sets, bogie frame, primary suspension, secondary suspension
and traction motor, etc. The wheel load is 25t. Primary suspension is fixed by primary spring,
vertical damper, and journal box pull rod. Secondary suspension adopts full side rubber
bearings with dampers in lateral and vertical directions. Traction force is transmitted by single
traction rod which is called push-pull rod. Train model is consisted of 4 locomotives model and
a simplified freight vehicle model, and there are coupler and buffer between vehicles. In order
to compare large rotation angle coupler with small rotation angle coupler, two kinds of couplers
are adopted. The freight vehicle just has the degree of freedom of running along the track.

3.2 Heavy haul locomotive coupler and buffer model
According to the train dynamics research, coupler and buffer system is usually simplified as
equivalent spring force elements; in fact, the coupler and buffer system is very complex,
especially the nonlinear stiffness characteristics of coupler head and knuckle pivot pin, and
damping characteristics of buffer. The hysteretic characteristics of coupler and the gap
between couplers do not get proper handle and there is rare research on the influence on train
dynamic performance caused by coupler and buffer system.
Detailed coupler and buffer model including coupler rotation, rotation stop characteristics,
coupler shoulder characteristics, and the dynamic impedance characteristics is setup; it can
simulate the impact of coupler with contact gap. Taking the large rotation angle coupler for
example, two connected couplers can be handled together, and the coupler head which can be
seen as a body are connected with both sides of the buffer with stiffness and damping
characteristics; Coupler body can rotate about the Z axis relative to buffer, and the rotation
angle is limited by the coupler shoulder. In addition, the coupler shoulders can provide a level
of moment reduction. The model of small rotation angle coupler is similarly to the model of
large rotation angle coupler; however, it only has the stop function but no coupler shoulder
settings. In addition, buffer character must be fully taken into account in the model.

4 Simulation Analyses
4.1 Analysis on coupler stability on straight line
The most serious stress of coupler and buffer of the heavy haul train are on condition of
braking. Especially in the dynamic braking condition that only the locomotive has brake force,
the coupler of locomotive suffers the greatest force of press in dynamic braking. The free
rotation angle of the small rotation angle coupler and the large rotation angle coupler are 10
degrees and 4.5 degrees, respectively. Taking the wheel set lateral force of the front
and behind the coupler three as the main evaluation index. The results of the two models are
shown in Fig.4, respectively. And in this case, the coupler force is 1000kN.

![Fig.4 Wheel set lateral force of the two kinds of models](image)

W_3_4 and W_4_1 indicate the 4th wheel set of 3rd locomotive and the first wheel set of 4th
locomotive in Fig.5, respectively. The value of wheel set lateral force are relatively stable when
utilizing large rotation angle coupler; while wheel set lateral force is huge at first then remaining
at a relatively low stable level for the model of small rotation angle coupler. It is caused by
different methods which the locomotive and coupler system are used to keep the two couplers
steady. Large rotation angle coupler equipped with coupler shoulders has the ability of
reposition. Coupler shoulder can not only provide reposition moment but also decrease the
coupler longitudinal pressing force. When it comes to the small rotation angle coupler, it can
only provide the capability similar to stop to limit coupler deflection through coupler yoke pin;
when the stop works, the coupler has a rigid impact on the coupler yokes, which leads to transient increase of wheel set lateral force. As the wheel set lateral force of the two coupler models have different performance, the locomotive with large rotation angle couplers becomes instability if wheel set lateral force comes close to 90kN, for the small rotation angle coupler, though the wheel set lateral force is quite big at the instant of yokes contacting with coupler, the force just lasts quite a short time, will not cause locomotive derailment. Therefore, it takes the later lasting wheel set lateral force as evaluation standard. The wheel set lateral force after 6s are taken as evaluation index.

Fig.5 shows the results of those two coupler models suffering different longitudinal coupler pressing forces. The maximum coupler pressing force which large rotation angle coupler can afford is nearly about 3000kN, while this value can not reach 2000kN for small rotation angle coupler. In comparison with straight track, the longitudinal coupler pressing forces which the locomotive is suffering on straight long ramp grade track is partly resulted from the gravity branch. The gravity branch of the 10000t freight train on the forward running direction on 10‰ slope straight line is about 1000kN. Hence, the maximum longitudinal coupler pressing force the locomotive can afford resulting from non-gravity factor for large rotation angle coupler and small rotation angle coupler are not bigger than 2000kN and 1000kN, respectively.

4.2 Buffer impedance characteristic analysis
4.2.1 Dynamic impedance characteristic
For the dynamic braking force which can be generated by HeXie locomotive is about 400kN, it is assumed that the dynamic braking force is 400kN and the calculation speed is 70km/h. Locomotive dynamic braking force begins at 3s and reaches at 400kN at 5s. The coupler pressing force suffered by the coupler three of 3rd locomotive is about 1200kN.

The dynamic impedance of buffer has little relation with the types of couplers. Hence, large rotation angle coupler equipped with coupler shoulder is taking as example. In order to study the movements of locomotive couplers, the 3rd locomotive and couplers on its rear (3rd coupler) are taken as examples, and the buffer stroke and coupler force under coupler pressing force are presented in Fig.6. In the calculation cases, the buffer has good dynamic impedance characteristic and can satisfy the requirement of 10000t heavy haul locomotive. Fig.7 shows dynamic value of wheel set lateral force and derailment coefficient of wheel sets before and behind 3rd coupler. Apparently, the derailment coefficient and wheel set lateral forces could satisfy the requirement of the standard at the calculated case. Results shows that
large capacity flexible buffers can satisfy the requirement of 10000t class heavy haul trains, and it can damp longitudinal impulse efficiently.

![Wheel set lateral force and derailment coefficient](image1)

**4.2.2 Static impedance characteristic**

Cycle braking of HeXie locomotives at long heavy down grade is taken as example in this case, and the coupler force of the locomotive is about 900kN for the 10000t train. The static impedance force of large capacity flexible clay buffers is about 1200kN, so quite large portion of buffers’ stroke consumed by compression results in the decrease of remaining capacity and resistance stroke. Except elastic clay buffers, a kind of friction clay type buffer are commonly used on heavy haul trains. Friction clay type buffers have all the advantages of friction buffers, such as low impedance, ordinary capacity and stable prosperity; more importantly, the static impedance is infinitely large theoretically.

Simulation results of cycle braking at long heavy down grade shown in Fig.8, give the results of elastic clay buffer and friction clay buffer, respectively. During the calculation, the coupler on the rear of 3rd locomotive suffers 900kN static press force at first, then 400kN dynamic press force is applied on the coupler.

![Coupler force and buffer stroke](image2)

Though the values of coupler forces are similar under different static impedance characteristic in cycle braking case on long heavy down grade, the strokes are quite different according to different buffers. Obviously, when static impedance forces is 1200kN and in cycle braking condition at long heavy down grade, there isn’t enough remaining capacity for coupler buffer system to damp longitudinal impact force further more. So the clay leakages and buffer damages problem will occur if the elastic clay buffer adopted. From the point of view of avoiding clay leakage and buffer damage, friction clay buffer can be used.

**5 Conclusions**

For railway vehicles with frequent braking, the reposition ability of the coupler and buffer system has significant influence on the train’s dynamics performance:

(1) For the large rotation angle coupler with coupler shoulder, wheel set lateral force keeps at a steady value under the longitudinal coupler press force; for the small rotation angle coupler without coupler shoulder, when the longitudinal coupler press force is given, a large peak value of wheel set lateral force will appear, and keep steady in smaller range;

(2) For the HeXie type locomotive adopting the large rotation angle coupler with coupler shoulder, the longitudinal coupler press force it can afford is about 3000kN; while adopting the small rotation angle coupler, the coupler force it could withstand is no more than 2000kN;
(3) Larger buffer static impedance characteristics is favor to maintain adequate remaining buffer stroke and capacity, and satisfy the requirements of further buffer longitudinal impact on the static condition, especially on the condition of cycle braking on long ramp down grade. As it has an effect on the train’s braking safety, the coupler with good reposition capability should be chosen priority on the heavy haul locomotive.

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