Technical Development of Heavy Haul Freight Wagons in Mixed Freight and Passenger Traffic

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Summary: Heavy haul transportation, as a major way to increase freight transportation capacity, has been widely used in the world. At present in many countries heavy haul transportation is undertaken mainly in special train lines. However Russia, China, India and some countries in Europe are different as they use same lines that heavy haul freight transportation operates as that passenger trains run. With increase in running speed of passenger trains, higher demand is raised for heavy haul freight wagons in such mixed freight and passenger traffic. This paper discusses factors that restrict development of heavy haul transportation in mixed freight and passenger traffic from perspective of technical development of heavy haul freight wagons in aspects of design concept, safety and reliability. It also introduces research and results on technical development of heavy haul freight wagons in mixed freight and passenger traffic in recent years in China.

Key words: mixed freight and passenger traffic, heavy haul freight wagon, development

Heavy haul is the main approach to improve cargo transportation capability which had been widely applied all over the world, at present, heavy haul transportation in many countries mainly adopt the special purpose line with simple transportation medium, however in Russia, China, India and European countries mainly adopt the manner of passenger car and wagons share the same track and as the travelling speed of passage car is improved gradually, and more strictly requirements are raised for the heavy haul technology under such condition. At present, Chinese railway revenue mileage has reached to 100,000 kilometers which is the second place in the world. Freight passenger mixed traffic is operated in Chinese railways, characterized by high speed, density and axle load. On existing lines, MTU running at 200–250km/h and general passenger train running at 160km/h are operated along with freight trains of 6000t. Given that trains run at high density, short interval time and great difference in speed between passenger trains and freight trains. Therefore it is required that freight cars have to have higher reliability.

1. CHARACTERISTICS OF CHINESE RAILWAY FREIGHT TRANSPORTATION

1.1 Great Demand yet Strained Capacity

Since 1990s, Chinese railway lines are strained intensively. Many busy main lines, especially for transportation of energies such as coal have already reached their full capacity. Chinese railway lines are only 6% of world railway lines in mileage, yet undertake 25% world freight turnover, the busiest in the world. To better meet needs of transportation development, many measures have been taken in Chinese railways to on one the hand gradually expand networks capacity by developing the potential, expanding inner capacity and reproducing, and constructing new lines, and on the other hand to further increase railway transportation efficiency and capacity by putting into service newly made and retrofitted heavy haul freight cars with increased speed of 120km/h.
1.2 Mixed Traffic Requires Higher Reliability of Freight Cars

Freight passenger mixed traffic is operated in Chinese railways, characterized by high speed, density and axle load. On existing lines, MTU running at 200-250km/h and general passenger train running at 160km/h are operated. For cargo transportation net, taking the strategy of developing "speed, density and weight" harmoniously, on speed, through technical upgrade and speedup and modification of existed wagons, standard wagon travelling speed has come to 120km/h, and on density, tracking interval on mainline reached to 7-10minutes which is the advanced level all over the world, on density, axle load of existed wagons is 23, and the 27t axle load general purpose wagon had been successful developed along with freight trains of 7000t. Given that trains run at high density, short interval time and great difference in speed between passenger trains and freight trains, even a normal failure will make great impact on safety of passengers and orderly transportation. Therefore it is required that freight cars have to have high reliability [1].

1.3 Management Pattern of Centralized Manufacturing, Service and Repair

The nationally centralized technical management of freight cars is adopted. Under organization of MOR, freight car designing and manufacturing enterprises and relevant research institutes work together to conduct basic research, develop products, rapidly break through key technological difficulties, and develop advanced and mature products. Then national wide freight car manufacturers simultaneously make preparations for production and start batch production in short time. By this way, the overall technical level of freight cars can be rapidly increased. Railway freight cars run on lines across 32 provinces and regions in the country with no fixed assignment. Inspection and repair factories, depots, workshops and routine inspection grounds across the country carry out inspection and repair according to uniform technical standards on nearly 700,000 freight cars. The centralized technical management of freight cars guarantees safe and orderly railway transportation given special conditions that railway freight cars are produced separately, run and repaired nationally for high efficiency and safety requirements.[2]

2. DEVELOPMENTS AND ACHIEVEMENTS OF CHINESE RAILWAY HEAVY HAUL FREIGHT CARS

In order to improve transportation capability under current tack condition, travelling speed of wagon should be increased to make it match with that of the passenger car, as well as the axle load should be increased for the same purpose.

2.1 General Purpose Freight Cars of 70t Payload, Example of Joint Development toward Increased Speed and Heavy Haul

Since 2006, Chinese railways have ceased the production of 60t payload freight cars and started the full production of new types of 70t payload freight cars of 23t axle load and with a speed of 120km/h (as shown in Figure 2). A full-scale upgrade of Chinese general purpose freight cars from 60t payload to 70t payload has been made. Presently, the inventory of 70t payload freight cars in China has exceeded 150,000. They run different railway lines across the country, and promote greatly transportation capacity. Especially, the integration of four technical indexes in freight train “23t axle load, 70t payload, 120km/h speed, and 5000-10,000 hauling tonnage” is suitable to special conditions and requirements of Chinese railways “mixed traffic lines, high efficiency and turnover, and safety priority”. A new path for railway development toward increased speed and heavy haul with Chinese characteristics is made[3].

2.2 Speed Up And Modification To Existed Wagons

Since 2005, existing 60t payload freight cars with Z8A bogies have been replaced by ZK2 bogies for 120km/h speed, along with modifications on the brake system so that ride quality and technical performance of existing freight cars can meet those of new type freight cars. By the end of 2011, more than 700,000 freight cars are able to run at 120km/h. The overall technical level of freight cars

Figure 1: Freight Car of 70t Payload
has been rapidly promoted in a very short time to meet the needs of substantial growth of transportation capacity. Consequently, strain on railway transportation is lifted rapidly and is get used to the mix running of passenger car and wagon.

2.3 Track Test And Research

2.3.1 Wagon Comprehensive Performance Test

Various types of speed up heavy haul freight cars including gondola car, covered car, flat car, tank car and hopper car have been subject to track dynamic tests for hundreds of times, these tests are used to make the actual track measurements on stationary and stability index, so as to verify the reliability and operation safety on designing and fabricating of the increased speed and heavy haul wagons.

Under organization of MOR, mass scale track comprehensive tests have been done on lines such as Jiao Ji line, Beijing Qin line, Sui Yu line and Long Hai line with travelling at a speed of 120km/h is up to 60% of the sector, covering track and bridges, freight cars, train crossing and hauling. The suitability of existing modified freight cars for increased speed and new type freight cars to existing track structure, turnout, roadbed and bridges, as well as the safety of freight cars crossing MTU are validated. Relation between speed up heavy haul freight trains and existing tracks and bridges are studied. All these have provided experimental experiences for launching heavy haul transportation on existing lines in China.

2.3.2 Reliability Test on Loop Test Line

From late 2003 to 2007, more than 50 heavy haul speed-up freight cars of 21t and 23t axle load of various types have been tested for reliability on the loop test line in China Academy of Railway Science, for total mileage of 350,000 km and up to 70% of the sector is at 120km/h speed[6]. The test is divided into two stages where car performance reliability is evaluated in the first stage and relation between service limit and car performance is studied in the second stage.

The first stage covers 180,000 km test lines, and overall test on car performance stability at 120km/h speed, matching of critical components, and impact of freight cars on tracks. Systemetic researches are made on influence of parameters matching of various components on car operation safety. Technical feasibility and reliability of speed up heavy haul freight cars are validated. The second stage covers 170,000 km test lines, and tests on wear of critical components affecting car performance at 120km/h such as wheel, adapter, wedge, journal box rubber pad and elastic side bearer. Studies on change pattern of wear vs. running mileage are conducted.

The four-year loop line reliability test is innovative in overall systematic researches on reliability of freight cars. Numerous test data and experiences have been accumulated, and change pattern of critical structure and components performance of heavy haul freight car vs. running mileage have been basically acknowledged. It promotes perfection of key technologies with respect to speed up and heavy haul transportation and provides scientific basis for full implementation of technologies with respect to speed up and heavy haul transportation.

2.4 Research In Key Technologies

2.4.1 Development And Application Of New Material

At present, Q450NQR1 high strength weather resistance steel with yield strength of 450Mpa is mainly applied to Chinese general purpose wagon, and its corrosion resistance is 100% improved than the common carbon steel, however, due to the variety of cargos and complex loading and unloading cases, corrosion on wagon body is still very serious. Under this condition, S450EW high weather proof steel and mating welding material are developed, which is 50% improved in corrosion resistance, increased in wagon maintenance interval and reduced in the cost.

2.4.2 Low Wheel-Track Dynamic Force Bogies

Frame brace bogie and swing motion bogie are applied. By application and perfection of wheel set elastic positioning technique, side frame swing technique and wheel set radial controlling technique, wheel track dynamic force is reduced, resulting in less track wear and damage. Devices such as frame brace, swing device, and radial device are fitted in bogies to control warp resistance to improve the ride quality of three-piece bogies. Compact bearing and axle are installed to relieve stresses so as to effectively improve safety and reliability of freight cars in service. Combined wedge, constant contact elastic side bearer and center plate wear plate, made of high molecular composite material are also fitted to reduce wear and improve ride stability of freight cars for conveniences of operation, inspection and repair[7].

2.4.3 Reliable Major Components

By replacement of rigid connection between frame braces by flexible connection, the frame brace device is improved in terms of fatigue life from 1.6 million km to above 5 million km. A forged coupler yoke is adopted to reduce risks caused by inner and external surface defects. A integral forged brake beam is installed to address standing quality issue of cracks on previous brake beams. Major components are more reliable in terms of fatigue, guaranteeing much safer service of freight cars[8].

2.4.4 Bolster And Side Frame Integral Core Casting

In the new technique of Grade B+ steel bolster and side frame integral core casting (as shown in Figure 2), 11 world advanced techniques such as bolster and side frame integral core making casting, liquid steel refining, surface penning, and ultrasonic and radiographic examinations are used to smooth inner cavity of bolster and side frame, eliminate original and potential defects, and consequently
to fundamentally improve casting quality of major components of freight cars.

2.5 Safety Monitoring

5Ts modern operation safety monitoring systems are used (i.e. THDS infrared bearing temperature monitoring system, TADS bearing acoustic monitoring system, TPDS dynamics monitoring system, TFDS freight car operation failure dynamic image monitoring system, and TCDS operation safety monitoring system) on main lines to carry out real time safety monitoring and alarming on status of key components of freight cars including bearings, wheels, brake beams, frame braces, bolster and side frames, and freight car performances. A safety monitoring system characterized by decentralized detection, centralized alarming, network monitoring and information sharing is formed, which guarantees safe operation of speed-up heavy haul freight cars.

3. DEVELOPMENT OF HEAVY HAUL TECHNOLOGY UNDER MIX RUNNING OF PASSENGER CAR AND WAGON

Under the mix running of passenger car and wagon, Chinese railway cargo transportation applied the strategy of developing "speed, density and weight" harmoniously, however at present, there is nearly no room for further development on speed and density, so the main approach is to develop heavy haul transportation by increasing axle load.

3.1 Research In Axle Load, Loading Density V.S. Track And Bridge

Axle load and loading density (weight per meter) is an very important index for checking if length of depot can be fully used to improve transportation capability, and also is the index directly in relating to bridge and track strength. The larger the axle load the more payload of single car, and the stronger transportation capability; the more loading density and the shorter the wagon and the larger tonnage within the effective depot length range, and whichever of above index is increased can improve the transportation capability by a large margin. But the increasing of axle load and loading density are both in relation with the strength of bridge and fatigue life, as a result of that, technology of track and bridge should be developed correspondingly while increasing axle load and loading density and they should have a proper binding point.

Effect to bridge by wagon axle load mainly reflects in local stress and overall stress. For structure or components bearing local stress, such as track structure, bridge deck and steel truss web plate, etc., the stress condition is directly in relating to magnitude of axle load. But for the overall stress, it is not only in relation to axle load but also the loading density, i.e.: axle load of wagon has large effect to little span bridge, and it also has large effect to big span bridge under the application of axle load and loading density. Though calculation, it is regarded that:

Axle load of Chinese general purpose wagon is increase to 27t, when loading density is no more than 8t/m, this only has large influence to strength and fatigue life, and when some weak or small span bridge of unclear standard is strengthened, and wagon with axle load of 27t can travel on the general purpose track.

3.2 Optimize Performance Of Wagon Suspension System To Realize Low-Wheel-Track-Force

Take the interaction between wagon and track and bridge, making comparison of bogie suspension system of different types of bogies through wagon coupling technology on the basis of research to bogie speed, travelling stability, reliability and conventionality to improve the low track performance of bogie.

The 27t axle load bogie adopts saddle shape journal rubber pad, two stage rigidity center suspension system and the calculation result show the track force of 27t axle load wagon is equivalent to the existed 25t wagons, see table 1.

<table>
<thead>
<tr>
<th>Wagon type</th>
<th>Force/kN</th>
<th>Speed /km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>25t axle load</td>
<td>P_i</td>
<td>276.2</td>
</tr>
<tr>
<td></td>
<td>P_2</td>
<td>200.0</td>
</tr>
<tr>
<td>27t axle load (low track force)</td>
<td>P_i</td>
<td>286.2</td>
</tr>
<tr>
<td></td>
<td>P_2</td>
<td>194.2</td>
</tr>
</tbody>
</table>
C70 general purpose gondola wagon to bridge is made and the result shows vertical dynamic coefficient and vertical movement caused by these two types of wagon to bridge are both equivalent.

3.3 Improve wagon tangent stability and curve negotiability to realize standard radial function

Simulation analysis is made by comparing optimized primary journal box elastic positioning frame brace bogie with axle load of 27t and ZK6 bogie, loaded car travels at 80km/h and negotiating curve of R600m, R800m and R1000m respectively, the average impact angle of leading wheel sets is reduced by from 43.75%~51.44%; when loaded wagon is travelling at 100km and negotiating curve of R800m and R1000m, the average impacting angle is reduce by 71.21%~80.6%. Curve negotiation ability is further improved [10], see table 2 and figure 3.

3.4 Research On Longitudinal Dynamics

as the increasing of marshalling length and train length, the longitudinal impulse in train must be increased, and force between coupler and draft gear and longitudinal bearing structure is worse, as a result of that, to reduce the longitudinal impulse between long and heavy train is the key technology of heavy haul all over the world. In order to reduce the longitudinal impulse caused by heavy haul wagon, analysis software such as STARCO is adopted to make research on longitudinal dynamics in train, and analysis are made to marshalling way and emergency brake of ten thousand ton train, cycle braking on long gradient, coupler force and draft capability when train starts and in other different conditions; research on property of coupler and draft system, brake system, train marshalling and operation are all made to provide theoretical basis for selecting parameter of coupler and draft gear system and brake system of heavy haul wagon, thus to improve the force on wagon body components, so as to improve the travelling reliability, stability and stationary of train and endure safety travelling of heavy haul wagons.

3.5 Research On Reliability

3.5.1 No Weld And Low Wear In Bogie To Make It Stable And Safe For Long Time Operation

Main wear parts on bogie are all made of non-metallic and metallic pairs to realize no wear or low wear, and the dynamic performance will not degrade after long

<table>
<thead>
<tr>
<th>Radius (m)</th>
<th>Speed (km/h)</th>
<th>Wagon type</th>
<th>Absolute value of average impact angle of leading wheel sets /mrad</th>
<th>Average impact angle reduce percentage on leading wheel sets between 27t and ZK6 bogie</th>
</tr>
</thead>
<tbody>
<tr>
<td>R600</td>
<td>80</td>
<td>C70</td>
<td>0.381</td>
<td>51.44%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27t</td>
<td>0.186</td>
<td></td>
</tr>
<tr>
<td>R800</td>
<td>80</td>
<td>C70</td>
<td>0.272</td>
<td>43.75%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27t</td>
<td>0.153</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>C70</td>
<td>0.093</td>
<td>80.64%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27t</td>
<td>0.018</td>
<td></td>
</tr>
<tr>
<td>R1000</td>
<td>80</td>
<td>C70</td>
<td>0.212</td>
<td>44.34%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27t</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>C70</td>
<td>0.066</td>
<td>71.21%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27t</td>
<td>0.019</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3: schematic of wheel sets curve negotiation
time running; welding structures are eliminated, support bracket, cross beam holder and side frame are cast together with bolster wear plate and riveted fulcrum seat to realize non-welding assembling which improved the reliability of bogie.

3.5.2 Fatigue Evaluation And Complete Wagon Fatigue Test Is Made To Improve Reliability Of Structure

The wagon body fatigue reliability is evaluated by nominal stress and structural stress method with Chinese measured load spectrum. Fatigue and vibration test bench, big component fatigue test bench are adopted for test verification and comparing with fatigue analysis result to improve heavy haul wagon research level and establish wagon body fatigue reliability evaluation system gradually.

3.5.3 Longitudinal Coupling Reliability of Train

Minimum tracking interval between wagons is 7 minutes, but general trouble shooting of railway wagon costs more than 2 hours, thus, when there is a separation of the train, it will cause huge damage to transportation organization and efficiency, as the increasing of wagon axle load and marshalling number, problem of separation becomes more and more obvious and the reliability of longitudinal coupling should be increased.

Yoke, coupler and knuckle are key technology to ensure safety of longitudinal coupling. Aiming at that, in recent years, forged yoke and heavy haul coupler and knuckle which are 10% increased in capacity on the basis of AAR standard are developed in China.

3.6 Dynamics And Bridge Response Test Condition

Track dynamic test and bridge response test were made in October of 2011 to general purpose gondola wagon and covered wagon with axle load of 27t (figure 6), and see figure 7 for marshalling of test wagon. When dynamic test was made, the speed started from 60km/h and increased by 10km/h. when the test car travelled across the bridge at different speeds, the test leading group would decide whether a high speed should be made for next test on the basis of fully demonstration and safety. The load track test lasted for 3 days and the maximum test speed is 120km/h while the empty test lasted for 1 day with the maximum test speed is 132km/h.

The test result shows that:

1. With the speed range of 130km/h, the 27t axle load general purpose gondola wagon and covered wagon has good dynamic performance and their stability is better than C70 gondola wagon equipped with ZK6 bogie.

2. When wagons are travelling across, the monitored indexes such as ratio between deflection and span, lateral amplitude and acceleration, vertical amplitude and acceleration of girder, lateral amplitude of bridge pier, and lateral displacement between girder and pier are all can meet requirement of "Code for rating railway bridges ", which means structure of bridge is safe.

4. CONCLUSION

Developing heavy haul transportation under mix running of passenger car and wagon provide higher requirement to heavy haul technology, and the relationship between speed, axle load and infrastructure should be matched reasonably; further research on key technology such as low wheel and track force; being innovative in transportation organizing pattern; setting up matching technical standard and make a firm foundation for pushing development of China railway heavy haul transportation.

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Figure 4: marshalling of tested wagons
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