Key Technology of Heavy Axle Load Locomotive

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Summary: This paper describes the necessity of developing locomotives with axle load of 30t and above. Based on the present status of the art of heavy axle load locomotives at home and abroad, the paper studies the traction characteristics of heavy axle load locomotives suitable for heavy-haul transportation in China, proposes that the 6-axle heavy-haul electric locomotives with axle load of 33t and axle power of 1600 kW shall be developed in China. The paper also discusses the technologies concerning traction systems, network control, locomotive body and bogie of such heavy axle load locomotives.

Index Terms: heavy-haul locomotive, traction characteristics, traction motor, network, locomotive body, bogie

1 INTRODUCTION

To solve the contradiction between the increasing requirement of national economy development on traffic volume and the severe insufficiency of railway traffic capacity in China is the core problem for implementing the scientific concept of developing and constructing harmonious railways. There are two approaches to increase traffic volume, one is to run more trains by shortening headway of train operation; the other is to increase the weight of each train. In China, the policy of mixed operation of passenger and freight trains has implied for a long time, the increase of traffic density is limited by conditions of locomotive, car, signal and traffic organization, so the increase of traffic density is already very difficult. However, to increase the load of trains is an effective and economical measure to increase traffic volume. Therefore, the medium-and long-term development program for railway network requires the separate operation of passenger and freight transportation should be realized on major busy trunk lines in order to adapt to the requirement of building a well-off society, passenger dedicated lines shall be constructed while heavy-haul and container transportation shall be developed.

In the world, a heavy-haul railway line is defined generally by three parameters namely annual traffic volume, train load and axle load, and should satisfy two of them at least. With development of heavy-haul transportation, its level is going up every year. See Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual traffic volume</th>
<th>Train load</th>
<th>Axle load</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>20 million t</td>
<td>5000t</td>
<td>21t and above</td>
</tr>
<tr>
<td>1994</td>
<td>20 million t (transport distance greater than 150km)</td>
<td>5000t</td>
<td>25t and above</td>
</tr>
</tbody>
</table>

The highest record of annual traffic volume of heavy-haul railway line covering a distance greater than 150km is created by China's Daqin line, which annual traffic volume in 2008 reached 340 million tons. The highest record of train load is 99743 tons made by Australian BHP. In terms of axle load, the United States, Canada, Australia, Brazil and Sweden use axle loads of over 30t. Although China is studying the technology concerning freight trains with 30t axle load, the maximum axle load in actual train operation is 25t.

According to experiences of international heavy-haul transportation development, increasing axle load is an important orientation for the development of heavy-haul transportation. The load carrying capacity of freight train
can be effectively increased and transport efficiency can be greatly improved by increasing the axle load. The adhesive weight can be increased by increasing the axle load of locomotive, which could provide necessary conditions for increasing the starting traction of the locomotive and improving the low-speed traction performance of the locomotive.

While the traction performance of locomotive is improved in the low speed sections by increasing the axle load of locomotive, but some difficult technical problems also occur. This paper will study the traction performance of the locomotive with axle load of 30t and above, recommend locomotive traction characteristics suitable for China's heavy-haul transportation, and describe the key technology of locomotives with axle loads of 30t and above according to the latest requirements for traction and driving systems, locomotive body, bogies and coupler buffer based on the recommended characteristics.

2 WORLD'S PRESENT TECHNOLOGY STATUS OF LOCOMOTIVES WITH AXLE LOAD OF 30T AND ABOVE

At present, the world's most advanced diesel locomotives with heavy axle load are manufactured mainly by GE and EMD, these locomotives are used in North America, Australia and Brazil. The most advanced electric locomotives with heavy axle load are manufactured mainly by Bombardier, Siemens, and Alstom, these locomotives are mainly used in Europe and South Africa. The technical parameters of major locomotive models are as follows:

2.1 WORLD'S PRESENT TECHNOLOGY STATUS OF LOCOMOTIVES WITH AXLE LOAD OF 30T AND ABOVE

<table>
<thead>
<tr>
<th>Locomotive model</th>
<th>Start traction (kN)</th>
<th>Max. speed (km/h)</th>
<th>Axle load (t)</th>
<th>Axle arrangement</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC4400</td>
<td>645</td>
<td>120</td>
<td>33</td>
<td>( C_0 - C_0 )</td>
<td>3240</td>
</tr>
<tr>
<td>AC6000</td>
<td>890</td>
<td>120</td>
<td>33</td>
<td>( C_0 - C_0 )</td>
<td>4476</td>
</tr>
<tr>
<td>AC6000-CW</td>
<td>890</td>
<td>121</td>
<td>33</td>
<td>( C_0 - C_0 )</td>
<td>4660</td>
</tr>
<tr>
<td>SD70MAC</td>
<td>780</td>
<td>113</td>
<td>33</td>
<td>( C_0 - C_0 )</td>
<td>3150</td>
</tr>
<tr>
<td>SD80MAC</td>
<td>820</td>
<td>128</td>
<td>32</td>
<td>( C_0 - C_0 )</td>
<td>3730</td>
</tr>
<tr>
<td>SD90MAC</td>
<td>890</td>
<td>128</td>
<td>32</td>
<td>( C_0 - C_0 )</td>
<td>4476</td>
</tr>
<tr>
<td>IORE106</td>
<td>1300</td>
<td>80</td>
<td>30</td>
<td>( 2(C_0 - C_0) )</td>
<td>10800</td>
</tr>
</tbody>
</table>

From Table 2, it can be seen that the maximum speed of heavy-haul locomotive is 80 - 120km/h, axle loads are generally greater than 30t, axle arrangement is basically \( C_0-C_0 \), the adhesion coefficient for electric locomotives is over 0.37 while for diesel locomotives is almost all over 0.4.

The use of the above high-performance heavy axle load locomotives has increased transportation efficiency significantly. On June 21, 2001, BHP IRON ORE operated 99743t trains pulled by 8 sets of AC6000CW AC-drive diesel locomotives. The train ran on the Newman Railway line with length of 426km and covered a distance of 276km with only a single driver. In order to optimize the distribution of traction force and braking force, the 8 locomotives were distributed in the train. Each two formed a group totaling three groups while the remaining two were arranged separately. All the 8 locomotives were controlled by Locotrol radio communication unit. The IORE106 locomotive of the Sweden LKAB company operated between Kiruna Iron Ore Mine in northern Sweden and Narvik in Norway with the maximum gradient of 17% and at a running speed of 60km/h, meeting the requirement of pulling 8160t in all weathers.

3 CHINA'S PRESENT TECHNOLOGY STATE OF HEAVY AXLE LOAD LOCOMOTIVES

Since 2004, China has successfully manufactured the HX series large power freight locomotives under the unified planning and leadership of MOR and through introduction, digestion and re-innovation of advanced technology. The basic parameters of these locomotives are shown in Table 3.
Table 3  Main technical parameters of China’s HX series large-power freight locomotives

<table>
<thead>
<tr>
<th>Loco. model</th>
<th>Starting traction (kN)</th>
<th>Max. speed (km/h)</th>
<th>Axle load (t)</th>
<th>Axle arrangement</th>
<th>Power (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HXD1</td>
<td>700/760</td>
<td>120</td>
<td>23/25</td>
<td>2(Bo - Bo)</td>
<td>9600</td>
</tr>
<tr>
<td>HXD2</td>
<td>700/760</td>
<td>120</td>
<td>23/25</td>
<td>2(Bo - Bo)</td>
<td>9600</td>
</tr>
<tr>
<td>HXD3</td>
<td>520/560</td>
<td>120</td>
<td>23/25</td>
<td>Co - Co</td>
<td>7200</td>
</tr>
<tr>
<td>HXN3</td>
<td>620</td>
<td>120</td>
<td>25</td>
<td>Co - Co</td>
<td>4660</td>
</tr>
<tr>
<td>HXN5</td>
<td>620</td>
<td>120</td>
<td>25</td>
<td>Co - Co</td>
<td>4660</td>
</tr>
<tr>
<td>HXD1B</td>
<td>584</td>
<td>120</td>
<td>25</td>
<td>Co - Co</td>
<td>9600</td>
</tr>
<tr>
<td>HXD2B</td>
<td>584</td>
<td>120</td>
<td>25</td>
<td>Co - Co</td>
<td>9600</td>
</tr>
<tr>
<td>HXD3B</td>
<td>584</td>
<td>120</td>
<td>25</td>
<td>Co - Co</td>
<td>9600</td>
</tr>
</tbody>
</table>

From Table 3, it can be seen that the maximum speed of China’s HX series large power locomotives has reached 120km/h. In respect of locomotive power, electric locomotives have 1200kW and 1600kW platforms for axle power while diesel locomotive already configured the 6000HP technical platform. The adhesion coefficient is 0.4 for electric locomotives and 0.42 for diesel locomotives.

The advent of the HX series large-power locomotives has increased transportation efficiency greatly. Take Daqin line for example, most of the locomotives in use are Model SS4 DC electric ones. Four locomotives are used to pull 20000t. The locomotives use resistance brake, and have a relatively low efficiency and power factor. Since using the HXD1 and HXD2 locomotives, one single locomotive can pull 10000t and the dual one can pull 20000t. The locomotives use regenerative brake, resulting in a power factor of 0.98 and locomotive efficiency of over 0.86.

By comparison between Table 2 and Table 3, it can be seen that the gap between China’s large power locomotives and foreign heavy-haul locomotives is that we have a relatively low axle load and smaller starting traction force. In order to further raise the technical level of heavy-haul locomotives in China, it is necessary to study the technologies concerning the use of axle load of 30t and above on the HX series locomotive platform.

### 4  STUDY OF TRACTION PERFORMANCE

The traction performance of a locomotive is the external expression of locomotive characteristics and an important basis by which the train operator formulates the traffic plan. As the locomotive used for heavy-haul transportation has to pull a heavier train, a higher requirement is imposed on the traction performance of the locomotive. The further increase in traction force is mainly restricted by the adhesion of the locomotive in low speed sections. The traction performance of a locomotive mainly depends on the factors such as axle arrangement, axle load, adhesion coefficient, starting traction force, speed and power.

#### 4.1 Adhesion Coefficient

The selection of the adhesion coefficient has a very important role on the traction characteristics of a locomotive. If the selected coefficient is too low, the adhesive weight of locomotive cannot be fully used; if the selected value is too high, the locomotive will easily idle and reduce the traction force on the contrary. The selection of adhesion coefficient is mainly based on experience and test results.

Through developing the HX series large-power AC diesel freight locomotives, we have become more experienced in selecting the adhesion coefficient. The adhesion coefficient of AC/DC diesel locomotive SS4 is 0.34, while that of HX series locomotives is mainly 0.37 – 0.4. Table 4 shows some results of the starting traction force test of the HX series locomotives. Figure 1 shows the site for testing maximum traction force of the HXD1 locomotive.

<table>
<thead>
<tr>
<th>Loco. model</th>
<th>Axle arrangement</th>
<th>Wheel diameter (mm)</th>
<th>Locomotive weight (kg)</th>
<th>Max. Traction force (kN)</th>
<th>Adhesion coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>HXD1</td>
<td>2(Bo - Bo)</td>
<td>1250</td>
<td>199107</td>
<td>767</td>
<td>0.393</td>
</tr>
<tr>
<td>HXD2</td>
<td>2(Bo - Bo)</td>
<td>1250</td>
<td>196090</td>
<td>792</td>
<td>0.412</td>
</tr>
<tr>
<td>HXD3</td>
<td>Co - Co</td>
<td>1250</td>
<td>149378</td>
<td>547</td>
<td>0.373</td>
</tr>
</tbody>
</table>

Figure 1  Train marshalling of HXD1 locomotive for test of maximum starting traction force

The data in Table 4 are those obtained on a dry tangent.
track with good adhesion conditions and new wheels. The maximum starting traction force of HXD1 and HXD3 remained to be 10km/h while that of HXD2 could reach such a value only at start. According to the test results and experiences in the world, the adhesion coefficient of axles load of 30t and above may be taken as approximately 0.4. Table 5 shows the starting traction forces obtained at various axle load when the adhesion coefficient is 0.4.

Table 5  Starting traction forces of locomotives with adhesion coefficient of 0.4

<table>
<thead>
<tr>
<th>Axle load (t)</th>
<th>Axle arrangement</th>
<th>Starting traction force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>C0 - C0</td>
<td>636</td>
</tr>
<tr>
<td></td>
<td>2(B0 - B0)</td>
<td>848</td>
</tr>
<tr>
<td>30</td>
<td>C0 - C0</td>
<td>706</td>
</tr>
<tr>
<td></td>
<td>2(B0 - B0)</td>
<td>942</td>
</tr>
<tr>
<td>33</td>
<td>C0 - C0</td>
<td>777</td>
</tr>
<tr>
<td></td>
<td>2(B0 - B0)</td>
<td>1036</td>
</tr>
<tr>
<td>35</td>
<td>C0 - C0</td>
<td>824</td>
</tr>
<tr>
<td></td>
<td>2(B0 - B0)</td>
<td>1099</td>
</tr>
</tbody>
</table>

4.2 Maximum Running Speed

One of the distinct features of China's heavy-haul railway transportation is to meet the requirement of national economy development. It is necessary not only to increase the train load, but also further increase the train speed and traffic density, thus increasing transportation volume. For locomotives with axle load of 30t and above, the increase in axle load and train speed will impose higher requirements on railway lines, bridges and other infrastructures as well as locomotive body, bogie and other key components.

Since the resistance to a running train increases to the square power of the speed, so the power needed for traction train will also increase after increase of train speed. Table 6 gives the power needed for 10000t trains to overcome the running resistance under different speed.

According Table 6, when the speed increases from 80 to 120km/h, each time the speed increases by 50%, the increase of power needed is 135%. Taking various factors into account and based on the experience of running heavy axle load trains, the maximum running speed should not exceed 100km/h.

4.3 Axle Power and Axle Load

As required by China's rules for calculating locomotive traction, a freight train should still have a residual acceleration of 0.005m/s² when it reaches the maximum speed on tangent line. From this, we can find the traction force and the necessary axle power at the maximum speed of 100km/h for pulling different train loads by locomotives with different axle loads. See Table 7.

\[
F_g = G \times \omega_0^g \times g \times 10^{-3} + P \times \omega_0^r \times g \times 10^{-3} + (P + G) \times (1 + \gamma) \times a
\]

where

- \( F_g \) —— Traction force at maximum speed in unit of kN
- \( a \) —— Residual acceleration, taken as 0.005m/s² as traction rules
- \( \gamma \) —— Rotary mass coefficient (0.06)
- \( \omega_0^g \) —— Unit basic resistance as per HXD1 locomotive
- \( \omega_0^g = 1.40 + 0.00380v + 0.00030v^2 \) N/kN
- \( \omega_0^r \) —— Resistance as per freight train with rolling bearing
- \( \omega_0^r = 0.92 + 0.0048v + 0.000125v^2 \) N/kN
- \( P \) —— Locomotive load in unit of ton
- \( G \) —— Freight train load in unit of ton
Table 7  Locomotive axle power under different traction loads

<table>
<thead>
<tr>
<th>Axle load (t)</th>
<th>Number of axle</th>
<th>Axle power needed by different traction loads (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>7000t</td>
</tr>
<tr>
<td>27</td>
<td>6</td>
<td>1123</td>
</tr>
<tr>
<td>870</td>
<td>978</td>
<td>1087</td>
</tr>
<tr>
<td>30</td>
<td>6</td>
<td>1135</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>882</td>
</tr>
<tr>
<td>33</td>
<td>6</td>
<td>1148</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>894</td>
</tr>
<tr>
<td>35</td>
<td>6</td>
<td>1156</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>902</td>
</tr>
</tbody>
</table>

In order to ensure the traction capability of the locomotive in high speed sections, it is necessary to select as high axle power as possible. The present maximum available power is 1600 kW and China has built a technical platform of large-power locomotives with axle power of 1600 kW.

According to the calculation results from Table 7, the necessary axle power of 6-axle locomotive used to pulling 10000t train is 1558kW ~ 1590kW, and the necessary power of 8-axle locomotive used to pulling 13000t train is 1522kW ~ 1554 kW. The axle power is just at 1600kW level.

Whether or not a 6-axle locomotive can pull 10000t and an 8-axle locomotive can pull 13000t depends on the verified calculation of the starting capability by limited track gradient.

The starting resistance of 10000t train on a 4% limiting track gradient (Daqin Line dedicated for coal transportation) is 736 kN and is 932 kN on a 6% limiting gradient of Class 1 trunk lines. The starting resistance to a 13000t train on a 4% limiting gradient (Daqin Line dedicated for coal transportation) is 956 kN and is 1211 kN on a 6% limiting gradient (Class 1 trunk lines). In order to ensure the reliable starting of a 10000t train on a 4% limiting gradient, the adhesion coefficient shall be considered 0.4 and the axle load of the locomotive should be taken as 33t according to Table 4. In order to ensure the reliable starting of a 13000t train on a 4% limiting gradient, the axle load of the locomotive shall be taken as 33t. This is so in view of making full use of the adhesive weight and power of the locomotive.

4.4 Traction Characteristic Curve

Figure 2 shows the traction characteristic curve of 6-axle locomotive with 33t axle load.

![Figure 2 Traction characteristic curve of 6-axle locomotive with 33t axle load](image)

From Figure 2, it can be seen that the 6-axle locomotive with 33t axle load can fully meet the requirement of pulling a 10000t train on the line with 4% limited gradient, and fully meet the requirement of pulling an 8000t train on China’s Class 1 trunk lines with 6% limiting gradient.
5 AC DRIVE SYSTEM

5.1 Main Circuit

The locomotive uses the voltage type AC-DC-AC electric drive mode now prevailing in the rail traction field. The main circuit is composed of high voltage circuit on the catenary side, main transformer, traction converter and ac asynchronous traction motor.

In order to cater for the large traction power of the locomotive, the voltage level of the electric drive system should be as high as possible. At present, the intermediate voltage of the HXD1B locomotive traction converter has reached 3775V. The developing heavy axle load locomotive should also have the voltage not lower than this level.

There are two control methods for controlling the locomotive motor drive, namely, bogie control and axle control. The advantage of bogie control is that the quantity of inverters can be reduced and thus the cost and maintenance expense will be decreased. Its disadvantage is that one inverter has to drive the motor on one bogie. The capacity of the inverter limits the increase in the axle power of the locomotive. In addition, when transfer of axle load occurs, or the wheel idles or skids, the use of adhesion is not so effective as in the case of axle control. When one traction converter fails, the entire bogie will lose power. The advantage of axle control is that one inverter drives one motor and this helps increase the axle power. When axle load transfers in the locomotive, or the wheel idles or skids, the locomotive may compensate for the transfer of axle load based on the actual adhesion, exercise effective control of idling and skidding, and make full use of adhesion. The malfunction of one inverter will only influence the power of one axle. When the traction equipment fails, its influence will be limited to the minimum scope. Since the large axle load locomotive with heavy axle load of 30t and above needs large power, so the axle control method shall be adopted in order to enable the locomotive to make full use of its adhesion and produce the maximum possible traction force.

Figure 3 is a typical main circuit diagram for the 6-axle locomotive.

5.2 Traction Converter and Its Control

The traction converter employs a four-quadrant PWM pulse rectifier on the power supply side. The intermediate DC loop has a 100 Hz series connected resonance circuit composed of a secondary filter reactor and a secondary filter capacitor to suppress the voltage pulsation of the intermediate DC circuit. On the motor side, a VVVF inverter is used.

The traction converter should employ the 6.5V IGBT components. The power module shall be so structured as to enable easy maintenance and repair. Water circulation cooling shall be used for efficiency and environment friendliness.

By continuous improvement of the control over converter on catenary side, the power factor of the locomotive can be increased further and harmonics can be reduced. At the same time, attention should be paid to the matching of the locomotive and the catenary to avoid oscillation between them.

The motor side inverter shall imply the vector control method which features good dynamic characteristics. In addition, control strategy shall be carried out so as to make optimum use of adhesion and enable the locomotive to produce the maximum traction force in all weathers and any rail surface conditions.

5.3 Traction Motor

The heavy axle load locomotive imposes higher requirements on the performance, capacity, structure, design and manufacturing of the traction motors. As the traction force of the locomotive increases with the increase in axle load, traction motors are required to produce greater torque. For application of heavy load traction, to increase the torque per unit weight is a goal that engineers have been making efforts to achieve.

The design of the electro-magnetic characteristics and insulation structure of the traction motors of a heavy axle load locomotive shall take into full consideration the overloading capability, reliability, availability, maintainability and safety. Efforts should be made to reduce the speed of the motor for continuous running so as to meet the requirement of the locomotive for starting and running on a long and steep gradient. The structure of stator iron core, the structure of rotator conducting strip circular, the sup-
port structure for the pinion wheel at the drive side and the lubricating method for bearings are key technologies deserving intensive attention in the course of research and development.

5.4 Auxiliary Power Supply

As shown in Figure 3, the auxiliary power supply of the locomotive employs the three phase ac system. The power to the auxiliary converter is fed by the intermediate dc loop in the traction converter. The auxiliary inverts the direct current to three phase ac current, which passes an auxiliary step-down transformer, is separated, filtered by the filter circuit, and then supplies power to the auxiliary power equipment of the locomotive. The quality of this power shall be up to that of the ground-based industrial electric power network.

There are two types of auxiliary inverters, namely, one with variable frequency variable voltage and one with constant frequency constant voltage. In the locomotive, equipment whose speed is regulated by varying the frequency, such as the ventilator of the traction motor, can be powered by the inverter of variable frequency variable voltage to save energy when the auxiliary machinery of the locomotive is in operation.

The auxiliary power supply system is designed with redundancy. When one group of power supply malfunctions, the other can still maintain normal power supply to the auxiliary system of the locomotive.

As the auxiliary inverter is fed with power by the intermediate DC loop of the traction converter, uninterrupted power supply is ensured during neutral section passing or other short-term power loss of the electric line.

6 TECHNOLOGY OF NETWORK CONTROL

Based on the network control technology of the HX series locomotives, which becomes mature in application, the following items will be studied further.

6.1 Enhancing the Study on Redundance of Key Equipments

Generally, heavy axle load locomotives are deployed on busy heavy-haul freight-dedicated lines, which impose much higher requirement on the reliability of locomotives. The design of onboard network control system with redundancy should be enhanced and improved. In addition to the redundancy of the bus and central control unit, important I/O interfaces and connecting cables shall also have redundancy. At the same time, in case of malfunction, the switch-over of redundant equipment should be appropriate and the impact on the operation of the locomotive shall be kept at a minimum.

6.2 Technology of Remote Radio Control

The train longitude force could be reduced efficiently, and the train braking performance could be improved by adapting power distribution and remote radio control technology. Accordingly the train could get higher running safety.

The traffic volume could be increased efficiently by adapting power distribution and remote radio control technology.

Accordingly the power distribution and remote radio control technology was introduced into Australia, Brazil, China and so on, after which applied successfully in north America. Up to now, China's combined trains which adopted power distribution and remote radio control technology have reached 20000t.

The experience obtained from the developing of heavy haul technology, the power distribution and remote radio control technology shall be one of the most important technologies. The key point of the technology is to realize convenient, real-time, reliable, communication among different type locomotives.

6.3 Study of Train-Wayside Communication Technology

Heavy axle load locomotives should have good and practical function of train-wayside communication to create conditions for application of IT for locomotive systems.

6.4 Technology of Diagnosis, Protection and Display

Heavy axle load locomotives should have a comprehensive diagnosing system, protective system and display system. This is especially important in case of combined train operation or remote radio control.

7 BOGIE AND LOCOMOTIVE BODY TECHNOLOGY FOR 30T AXLE LOAD

7.1 Bogie

The bogie for the 33t axle load will draw fully on the experience obtained from the operation of the HX series locomotive bogies with 25t axle load. At the same time, in order to make it suitable for 33t axle load, necessary adjustment should be made on the bogie structure.
7.1.1 Bogie Frame
All bogie frames of heavy axle load locomotives operating in North America are made of cast structures. In China, the maximum axle load of the locomotive is now 25t and the bogie is made of welded box beams without exception. The 30t axle load locomotive operated by Bombardier in North Europe also uses welded frame for the bogie.

In view that in present China, cast structure frames of bogies are very few, and the technology of welded frames is relatively mature, it is planned that the 30t axle load locomotive shall employ a welded frame.

The design standard of frame strength is still the railway industrial standard TB/T 2368 in China. Through a 3-D design, strength calculation, mode analysis, fatigue test, dynamic stress measurement and other technical means, the strength of the bogie frame shall be ensured. After the bogie frame has been trial manufactured, its strength will be checked by static strength test and fatigue strength test as to see if it is up to standard.

Owing to the impact of increasing axle load, the bogie frame will have to bear an even greater static and dynamic load, therefore measures shall be taken in respect of materials, plate thickness, local structure processing and welding technology to make sure that its strength meets the requirement.

7.1.2 Bogie Suspension Device
In consideration of the relatively great static weight of the wheel of the 30t axle load locomotive, the dynamic acting force between wheel and rail increases correspondingly, therefore the design of the bogie suspension device shall incorporate appropriate measures to reduce this type of dynamic acting force.

It is planned that rubber-metal pad will be used for the secondary suspension of the bogie to avoid excessive vertical displacement of the secondary suspension and the impact on the coupler's working height due to relatively large dynamic vertical load when flex coil springs are used.

The primary suspension of the bogie may use the double draft bars and double helical springs now in general use in our locomotives, but their parameters have to be optimized in a special way.

7.1.3 Bogie Wheel Axle Drive Unit
The basic structure of the bogie wheel axle drive of the current HX series electric locomotive can be used for the 30t axle load locomotive. From the analysis results of wheel strength now available, the wheel diameter can still be taken as 1250mm. Alloy steel should be considered for axle material so as to cater for the strength requirement in conditions of 30t axle load.

Axle-hung suspension can still be used for motor suspension. Class I gear drive shall be employed. In consideration of the relatively low running speed of the 30t axle load locomotive, drive ratio shall be designed as 6 to 8, under which condition the gear strength shall be specially designed to satisfy the requirements of line delimitation, 30t axle load and big drive torque.

Special matching shall be carried out between wheel material and wheel tread to reduce the wear and tear of wheel and rail.

7.1.4 Draw Gear
The low-position single draw bar currently employed by HXD3B locomotive can be used to effectively relay traction force, braking load and reduce the transfer of axle load.

7.2 Locomotive Body
The locomotive body will still be a full welded steel structure for integral bearing, which is composed of the driver's cabin, underframe, frame for equipment installation, side wall and detachable roof.

In order to match its operation condition, the strength level of the 30t axle load locomotive body should be raised on the basis of the current HX series locomotive. Its longitudinal compressive load shall be increased from the present 3000kN to 4000kN, and its longitudinal tensile load from the current 2500kN to 3300kN.

In order to increase the strength of the locomotive body, firstly, it is necessary to ensure the dimensions of the locomotive body are big enough by reference to the overall parameters of the body and full use of the clearance in the design of the external dimensions of the locomotive body so as to give the body a sufficient strength and ease the weight distribution of the heavy axle load locomotive.

The driver's cabin will still be a framework structure, but the beams and columns have to be strengthened to meet the increased safety requirement for the cabin.

The underframe is the main loading part of locomotive body. It not only carries the vertical load, but also passes on the longitudinal force and a variety of dynamic loads of the locomotive. With increasing of locomotive axle load, the interaction of these loads and their impact become more complex. Therefore, the heavy axle load locomotive has a higher requirement for the strength and rigidity of the underframe. From the comparison of the underframe structure layout of existing locomotives, when technology permits, major components shall be made of a welded structure of thick plates and pressed shape pieces in permitted technique range. All beams shall be of a
closed structure, and the structural form of the mid beam arranged longitudinally along the underframe is a key item of the design research.

It is recommended that the side walls shall be a frame structure with good functionality and workability. A further study shall be carried out for the impact of the upper chord beam at the large interface of the side wall on the torsional rigidity and underframe rigidity to bring into full play of overall carrying capability.

7.3 Coupler and Buffer

In order to meet the application requirement of the 30t axle load and match it to the strength of the locomotive body, special study of the coupler and buffer shall be carried out.

The structure design of the coupler and buffer shall draw on the experience obtained from the operation of the HX series locomotives. These experiences include:

1. The coupler and buffer shall have the function of automatic alignment to reduce the impact of the lateral component of the coupler force on the lateral dynamics of the locomotive;

2. The free deflection angle of the coupler shall be strictly controlled;

3. Anti-decoupling structure shall be adopted to avoid the accidents caused by coupler decoupling and train separation;

4. Energy absorbing unit shall be fitted between the buffer and the locomotive body so as to protect the locomotive body, personnel inside and equipment safety in case of abnormal longitudinal impacts.

8 CONCLUSION

In addition to the key study of technologies of AC drive, network, heavy axle load locomotive body and bogie described in this article, it is necessary to study the technologies of heavy axle load locomotive braking, large power diesel engine and other key technologies. The 6-axle 9600kW heavy load electric locomotive with 33t axle load recommended in this article ensures not only that a relatively high traction force will be available when the locomotive is running at low speed, but also that the locomotive will completely meet the requirement for power at high speed, pulling a 10000t train on a 4% limiting gradient and pulling a 8000t train on a 6% limiting gradient.

REFERENCES

