Study on Simulation of ECP/DP on Heavy-haul train

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Abstract: According to the requirement of railway transportation, China will run 20,000-ton heavy-haul train on line between DaTong and Qin Huangdao, for which ECP (Electronically Controlled Pneumatic braking) or DP (Distributed Power) will be adopted. Through computer simulation method, influence on braking distance and in-train longitudinal force of Chinese heavy haul train after adopting ECP or DP technology has been studied. Mathematical models of ECP and DP have been constructed, based on which ECP braking simulation module, DP simulation module and draw-bar force calculation module have been developed under Visual C++ platform. Simulation of ECP and DP are conducted with this software. For 10,000-ton and 20,000-ton heavy-haul train, with ECP, DP or conventional air brake system, simulation calculations have been made respectively and analysis and discussion of the calculation results have been conducted. Calculation results show that compared with conventional air brake system, ECP or DP can reduce the brake distance and in-train longitudinal force remarkably. For example, adoption of ECP has shortened the braking distance by 21% to 63%.

Key words: ECP, DP, Heavy-haul train; Brake system; Simulation

1. Foreword

Currently, railway transport has become a “bottle neck” restricting the development of national economy, which is mainly reflected on such circumstances as tight energy supply of power coal and petroleum and “restriction of power consumption” in various provinces of South China. The transport demand on power coal and petroleum has abruptly increased. And the State Council requires that the railway should complete transport task of coals over 1,000 million tons in 2004. Meanwhile, the material transport volume like petroleum, fertilizer and crops are going up at great extent too. The Ministry of Railways requires that Daqin railway line (Datong to Qin Huangdao) must complete the coal transport assignment amounting to 150 million tons in 2004, which is to be increased up to 200 million by year 2005.

Under the situation that the annual transport volume increases up to 200 million tons, the traction weight between 5,000 tons to 10,000 tons for each heavy-haul train already can not meet the transport development requirement for Daqin railway line, which must be doubled. Therefore, it is highly urgent to run 20,000 tons heavy-haul unit train.

The main problem involved in running of 20,000 tons heavy-haul train is safe braking operation:

1. Serious accident of coupler break caused by greater longitudinal coupler forces

The 20,000-ton heavy-haul unit train consists of 200 gondola cars of 25t axle load, with length of the total train over 2700 meters. If the existing air brake system still is adopted for operation of the train, the limiting velocity of 300m/s of the air pressure wave propagation can still not be exceeded, notwithstanding that the current 120-type brake system has been up to the internationally advanced level in terms of the air brake performance and the emergency brake propagation rate has reached 250~280m/s. In case of emergency application, it will take a full 10 seconds to transmit a brake pipe reduction from the locomotives to the last car in a 20,000-ton train, which, consequently will cause inconsistent braking force at the front and rear part of the train during normal and emergency brake, and produce great coupler force and violent longitudinal impulsion in the train, thus posing serious coupler break and derailment accident.

2. Malfunction accident caused by too long recharging time

There is 12% long steep downgrade on Daqin railway in the loaded car direction. Adoption of the current air brake system by 20,000t heavy-haul unit train on the 12% long steep downgrade is likely to cause out-of-control of the train speed, or result in malfunction in case of severity, thus severely threatening running safety, which is attributed to lack of graduated release function and too long recharging time.
Ever since the 1980s, heavy-haul unit trains are popularly available for mass transport in USA, Canada, Australia and South Africa. According to the experience accumulated by foreign countries in running heavy-haul trains, adoption of air brake system (ABDW, ABDX) will frequently cause coupler break and derailment accidents when the traction weight is over 15,000 tons. The American railway statistics show that 70% among all the accidents are coupler break accidents. The direct loss caused by such accidents in the US every year amounts to 50 million US dollars (excluding indirect impact on transport and personnel).

To solve the foregoing serious safety related problems, in 1995 the US started its research on application of ECP in the heavy-haul unit train. In 1997 it was installed in the train for test run. In 1999 AAR prepared the ECP codes and standards. To date, ECP system has been used in the heavy-haul unit trains in US, South Africa and Australia, etc. Over 10,000 trains have been installed such system and it has achieved sound application effects.

Development of DP (Distributed Power) system is originated in US. The locomotive wireless remote synchronous traction control (LOCOTROL system) test was first conducted in the US in 1959. Afterwards, many renovations were made for such system in US. And in 1970s the DP technology was approaching to maturity, then it was used in Australia, Brazil and Algeria. From 1980s to 1990s, the computer-based wireless remote control device (the third generation of LOCOTROL system) was developed by the American Harris and then promoted in the US and Canada.

2. Principles of ECP/DP

2.1 Principles of ECP

ECP brake system utilizes the conventional auxiliary reservoir and brake cylinder, in which the air is still the main source of brake force. However, the air is not functioned as the transfer medium for the brake command. As the main air pipe, the train pipe keeps filling air to the auxiliary reservoir, thus ensuring its on-call status all the time.

During braking operation, the locomotive transmits various information like brake command and object pressure to cars by way of the ECP brake system, while the car control unit will control the air charging from the auxiliary reservoir to the brake cylinder in accordance with the control signals. In case of release, the car control unit will control the braking cylinder to vent in accordance with the control signals. Thank to the graduated braking and graduated release function of the ECP brake system, the train operation and speed control are more flexible.

The communication devices in ECP brake system can not only transmit the control command to the cars but also receive the car status information. By this way, safety status and performances of the whole train can be monitored by the locomotive. The minimum limited monitoring requirements are specified in the AAR standard, which focuses on the safety of ECP car control unit (CCD) and the main braking data related to pressure, such as the pressure in the brake cylinder, train pipe and auxiliary reservoir.

2.2 Principles of DP

The DP system communicates control signals through a data radio link so that it gives synchronous control of remote units as desired by the driver. The control of the automatic brake from two or more points in a train remarkably improves the performance of the brake system, including faster braking propagation rate and release propagation rate. Distribution of power in the train can greatly reduce the traction force at the train front, which can improve adherence between the wheel and the rails.
During brake, such information as braking command and object pressure, etc. is transmitted to various multi-locomotives by the lead locomotive through the communication devices of DP system. After receiving brake command, multi-locomotives will apply brake. In this case, the brake wave distribution is illustrated as figure 2. It can be seen that there are multiple brake signal sources in the train. Hence, propagation of the brake wave in the train is in two ways other than in the direction of from the train front to the rear as shown in the conventional air braking system. Therefore, compared with the conventional air brake, the time difference between receipts of the brake signals by various cars is greatly reduced, which can help to reduce the longitudinal impulse in the train.

2.3 Benefits of ECP/DP

ECP braking represents the most significant change to fright railway braking systems since the original air brake invention by George Westinghouse in the late 1800's. Compared with conventional air brake, ECP has the following advantages:

- shorter stopping distances
- lower in-train forces, with related equipment wear and tear
- easier train handling and ability to increase train length and /or weight
- energy savings
- cycle time reduction
- lower wagon maintenance costs

Besides, ECP provides a train level communication network, which is shared by all the wagons along the train. By adding sensors and actuator functions on wagons, the status of all wagons can be monitored. In the future, the intelligent monitoring network over the whole freight transportation system is possible.

With DP, the following advantages can be achieved over conventional air brake:

- Charging time is reduced;
- Brake applications and releases are faster
- Power efficiency and overall tonnage are enhanced
- More rapid acceleration and deceleration
- Stopping distance is reduced
- Reduction of draft forces on head end of the train

3. ECP mathematical model

It is requested that the ECP mathematical model shall be able to reflect the action effects of the ECP brake system. On the basis of foregoing fundamental principles of ECP, we can come to a conclusion that comparison of the conventional air brake system shows that the action effects of ECP brake system are determined by such two aspects as the brake signal transmission speed and boost features of the brake cylinder, they are not related to the performance of the distributing valve. Besides, they are closely related to the factors like the car configuration (weight and length, etc.), performance parameters of the fundamental braking device (leverage ratio, brake rigging efficiency) and friction properties of brake-shoes, etc. However, those factors have the same impact on ECP braking system as that on the air brake system. Hence, the key for establishment of ECP mathematical model is to establish correct brake propagation ratio model and pressure increasing model for the brake cylinder.

3.1 Response time

The conventional air brake system describes the brake signal propagation speed in the train with the braking propagation rate. This parameter impacts the synchronization of the brake application of cars in the train, which further impacts the longitudinal impact in the train. However, the ECP system sends the brake control command in the train network by way of broadcasting, where the transmission time can be neglected, we can deem that the control signals are received simultaneously by various cars. But there is a response time between sending of the brake control command and receipt of such signals by various cars. The response time is influenced by following factors: 1) network bandwidth; 2) networking protocol; 3) network status

Presently, Lonworks technology is adopted by the ECP system, with the power line as the signal transmission medium. The compatible power line transceiver includes PLT-20, PLT-21 and PLT-22. For PLT-20 the data transmission rate is 5.4 Kbps (see table 1), i.e. the network bandwidth is 5.4Kbps.

The networking protocol will affect the data package size of the control command and the additional data flow brought by data verifications. According to S-4230-03, the longest communication command shall have 40 bytes.

By comprehensive analysis of abovementioned influencing factors, 0.3 s shall be taken as the response time.
Table 1 normal LonWorks channel types

<table>
<thead>
<tr>
<th>Channel type</th>
<th>Medium</th>
<th>Bit rate</th>
<th>Compatible transceivers</th>
<th>Maximum devices</th>
<th>maximum distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP/FT-10</td>
<td>Twisted-pair, Free or bus Topology, opt. Link power</td>
<td>78kbps</td>
<td>FTT-10, FTT-10A LPT-10</td>
<td>64-128</td>
<td>500m (free topology) 2200m (bus topology)</td>
</tr>
<tr>
<td>TP/XF-1250</td>
<td>Twisted-pair, Bus topology</td>
<td>1.25Mbps</td>
<td>TPT/XF-1250</td>
<td>64</td>
<td>125m</td>
</tr>
<tr>
<td>PL-20</td>
<td>Power line</td>
<td>5.4kbps</td>
<td>PLT-20, PLT-21, PLT-22</td>
<td>Environment dependent</td>
<td>Environment dependent</td>
</tr>
<tr>
<td>IP-10</td>
<td>LonWorks over IP</td>
<td>Determined by IP network</td>
<td>Determined by IP network</td>
<td>Determined by IP network</td>
<td>Determined by IP network</td>
</tr>
</tbody>
</table>

3.2 Pressure increase curve of brake cylinder

For the conventional air brake system, the BC pressure increase curve is related with many factors including performance of the triple valve, position of the car in the train and the pressure reduction. However, for ECP brake system, because air is continuously filled to auxiliary reservoir by the brake pipe and pressure reduction of brake pipe is not any more regarded as the brake signal, therefore, we can deem that the BC pressure increase curve is basically not related with the car position. Instead, it is related to the brake control command type, CCD control strategy and performance of air charging and venting equipment. Figure 3 shows the schematic diagram for charging and venting of the brake cylinder in ECP model.

![Fig. 3 Charging and venting for brake cylinder in ECP model](picture)

3.2.1 Brake control command types

ECP system uses train brake command to substitute for BP pressure reduction in conventional pneumatic brake and define the objective BC pressure. For different objective pressures, the BC pressure-increasing processes and the final results are different. According to technical specification (2004) for cable electronically controlled pneumatic system by MOR, the relationship between brake cylinder objective pressure and brake control command is as illustrated in Table 2.

Table 2 Brake control command specified in ECP technical specification of MOR

<table>
<thead>
<tr>
<th>Number</th>
<th>Train brake command (TBC)</th>
<th>Target brake cylinder pressure (BCP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0%</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0&lt;TBC&lt;-10%</td>
<td>BCP=MSP (Minimum Service BCP), the minimum brake cylinder pressure is aspre-configured, saved in CID with default being 7psi</td>
</tr>
<tr>
<td>3</td>
<td>10&lt;TBC&lt;-100%</td>
<td>BCP= m(x)+ b where m = (FSP-MSP)/(100-10) b = FSP-m(100) x = TBC</td>
</tr>
<tr>
<td>4</td>
<td>TBC=100%</td>
<td>Full service BCP = 420kPa</td>
</tr>
<tr>
<td>5</td>
<td>TBC=101%</td>
<td>Emergency brake BCP = 420kPa</td>
</tr>
</tbody>
</table>
In this table, CCD uses the following formula to calculate brake cylinder pressure for full service brake:

\[ FSP = \frac{NBR \times W}{C} \]  
\[ C = A_p \times LR \times EFF \]  

where:

- \( \text{NBR} \): net braking ratio
- \( A_p \): area of the brake cylinder piston
- \( LR \): leverage ratio
- \( EFF \): brake rigging efficiency
- \( W \): car weight
- \( FSP \): full service brake cylinder pressure

The Constant \( C \) is programmed into CID module.

In order to ensure that a sufficient amount of full service BCP is available, a minimum full service BCP limit is needed. The limit shall be 30% of its maximum gross rail load full service BCP or 20.0 PSIG, whichever is higher. In addition, to ensure that a sufficient supply of air exists to provide emergency BCP, the maximum full service BCP Limit shall be determined by the formula:

\[ FSP_{\text{max}} = \text{brake pipe constant pressure} \times RC \]  

Where, \( RC \) is a constant for auxiliary air cylinder, with \( RC=0.71 \).

When calculating the maximum full service pressure, CCD also takes into account of other factors. For example, the actual net braking ratio does not exceed the value allowed (25% as specified by S-4200).

### 3.2.2 CCD control strategy

CCD control strategy refers to the response logic of CCD to brake control command TBC. After receiving TBC, CCD analyzes the command to attain brake cylinder objective pressure, controls opening/closing of inflation electromagnetic valve by preset logic, admitting auxiliary reservoir pressure air into brake cylinder until the objective pressure is attained.

### 3.2.3 Features of charging/venting equipments

In ECP system, the charging/venting equipments that relate to brake operation include auxiliary reservoir, brake cylinder, charging and venting electromagnetic valves. After receiving brake control command, various cars, according to brake cylinder objective pressure, starts relevant electromagnetic valves control brake cylinder charging or vent. When brake cylinder is being charging, such factors as electromagnetic valve drift diameter, pressure difference between AR and BC, and AR and BC dimensions will influence the brake cylinder pressure increase curve; In case of BC vent, the electromagnetic drift diameter will influence the BC pressure reduction curve.

### 3.2.4 Experiment result

The full service application test result of ECP system obtained on 150-car test rig in the US is shown in figure 4. Detailed test parameters: 150 cars, overlay EP full service brake, brake pipe being 3300 meters long. AR and BC pressures of 1st, 75th and 150th car are tested.

![Fig. 4 Brake cylinder pressure increase curve for ECP, full service brake, provided by NYAB](image)

**Note:** 1 psi = 6.89 kPa
4. DP Mathematical model

According to DP theory, when conducting DP brake process simulation, we can split the whole train into short consists (unit consists) for separate calculation, which involves two problems, 1) train splitting method; 2) short consists brake simulation.

4.1 DP unit consists creation

In power distribution control system, locomotives distributed in the train communicate through radio network. When creating unit consists, the following assumptions are made:

1) Ignore control signal transmission time and assume various locomotives operate completely synchronous;
2) Transmission rates of brake wave in two directions are equal, i.e., the brake wave generated in the middle locomotive is transmitted both backward and forward at the same speed.
3) Ignore the influence of venting load difference of locomotives on braking propagation rate, i.e., assume that braking propagation rates produced by locomotives are equal no matter whether its in the middle or at the ends of the train.

Based on assumptions mentioned above, we can conduct train splitting by an even-distribution method. As displayed in the fig. 5, the train can be divided into four and three short consists.

4.2 Unit consist brake simulation

Using empirical formula to calculate braking propagation, pressure gradient distribution and brake cylinder charging process in the train, and then calculate brake force on the basis of brake cylinder pressure.

5. Software implementation for simulation

We develop simulation codes by expanding on the basis of the Traction Simulation Software by China Academy of Railway Sciences, which provides locomotive&Car model and line model, and has a relatively sound and complete Rolling stock and line database. In view of the real situation on the Daqin railway, we add the DJ1 and C80 into the Rolling stock database. Newly developed ECP and DP simulation modules are inserted into the original software. ECP and DP characteristic parameters are attached to the end of relevant data file in order to maintain full compatibility with the original software.

5.1 Software implementation of main ECP features

In light of real situations with China railway industry, the following issues are considered in software implementation:

1) As stipulated in ECP system technical specifications by MOR, the 120 brake of China does not need emergency pressure increasing function. Therefore, set objective pressure of emergency braking equal to that of full service braking (loaded car) at 420kPa (constant pressure = 600kPa);
2) In ECP system, one electromagnetic valve for charging is adopted. The pressure increase in BC is controlled by opening/closing the valve. According to ECP system technical specification by MOR and overseas situations, the BC pressure increase time in case of full service brake is 10s, while that in case of emergency brake is 7s~9s (take 8s).
3) The brake cylinder pressure increase curve shown in Fig. 4 is taken as basis for simulation. The constant pressure for heavy-haul freight train in China is 600kPa, accordingly the maximum BC pressure $P_z=435$kPa.
4) Due to the resistance of brake pipe wall and leakage along the brake pipe, there is pressure gradient along the brake pipe, that is to say, there is difference between AR pressures of front car and end car, which will influence charging process of BC and its objective pressure.

In software design, the main features of ECP brake system are achieved through different methods. The braking propagation rate is designed to be a user-editable variable and an external interface is provided to modify this parameter.

There are many factors influencing BC pressure increase curve. For simplification, we take the existing experiment result curve as the simulation criterion for pressure increase curve, disperse and match the experiment curve, take its tendency line as the standard curve and save up the feature data of that curve in files, including number and parameters of inflexion points. This way, in software implementation, it is possible to obtain BC pressure in different feature zones by piecewise matching and interpolation. Fig. 6 is the BC pressure increase curve adopted for this software (full service brake).

BC pressure (0.1 MPa)

Fig. 6 Fitting curve of BC pressure increase test data (1-6 are inflexion points)

5.2 Software implementation for major DP features

In DP simulation, we focus on splitting of train, i.e., on the basis of train make-up and locomotive locations, to split long train into a series of short units, the pneumatic brake within which is simulated with empirical formula. In this simulation, we will neglect for now the delay in radio communication, with DP control being synchronous control.

5.3 Calculation procedure

Fig. 7 shows the procedure for ECP system simulation. The program generates TBC control command according to user's input and calculates BC pressure of each car, and then calculates brake efforts. The brake efforts are sent to the draw-bar force calculation module and dynamics module to calculate such parameters as draw-bar force and braking distance. The procedure of DP simulation module similar to that of ECP module.
Fig. 7 Simulation calculation flow in ECP brake procedure

Fig. 8 Interface for ECP module
6. Simulation example

6.1 Calculation schemes

10,000-ton and 20,000-ton trains are built, the make-up details are as follows:
10,000-ton: DJ1×2+102 C80 (ECP) or DJ1+ 51 C80+ DJ1 +51 C80(DP)
20,000-ton: DJ1×4 +204 C80(ECP) or (DJ1+ 51 C80)×4(DP)
where, parameters for C80 simulation are as below:
- Net weight: 13.5t
- Loading capacity: 76.5t
- Brake cylinder: 2 10-inch brake cylinder
- Brake shoe model: new high friction-coefficient composite brake shoe

Simulations are done on the basis of ECP, DP and traditional pneumatic brake modes under the same line conditions for each make-up. In calculation, apply traction for some time to make the train in stretch status before coasting, then apply emergency brake when the target speed is attained. For calculation schemes, see table 3.

Table 3 Simulation calculation schemes

<table>
<thead>
<tr>
<th>Number</th>
<th>Make-up</th>
<th>Initial brake speed (km/h)</th>
<th>Working mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>scheme 1</td>
<td>10,000 ton</td>
<td>90</td>
<td>Emergency brake</td>
</tr>
<tr>
<td>scheme 2</td>
<td></td>
<td>70</td>
<td>Service application</td>
</tr>
<tr>
<td>scheme 3</td>
<td></td>
<td>30</td>
<td>Emergency brake</td>
</tr>
<tr>
<td>scheme 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>scheme 5</td>
<td>20,000 ton</td>
<td>90</td>
<td>Emergency brake</td>
</tr>
<tr>
<td>scheme 6</td>
<td></td>
<td>70</td>
<td>Service application</td>
</tr>
<tr>
<td>scheme 7</td>
<td></td>
<td>30</td>
<td>Emergency brake</td>
</tr>
<tr>
<td>scheme 8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Besides, train configuration is also important issue for running 20000t heavy haul train. Two train configurations are considered which are as follows:

- 2×10000t: (DJ1×2 +102 C80)×2
- 4×5000t: (DJ1+ 51 C80)×4

6.2 Result analysis

For the 20,000-ton train with ECP, the simulation results for BC pressure increase curves for 1, 50, 100, 150 and 200 car are shown in figure 9.

![Fig. 9 Simulation result of BC pressure increase](image-url)
From the figure it can be seen that the maximum BC pressure of cars at the end of the train is different from that of cars at the front of train due to pressure gradient in brake pipe. The influence of AR pressure difference on charging process can be temporarily ignored.

Fig. 10 gives simulation result of BCP increase curve in case of emergency application for DP train. Table 4 shows the simulation results for braking distances. We can tell that, in case of emergency brake, ECP has limited improvement on 10,000-ton train. However, for 20,000-ton train and service brake, ECP shorten stopping distance remarkably. The reasons are as follows:

1) Conventional pneumatic brake takes pressure signal as the control signal. The longer a train is, the more a control signal attenuates, but there is basically no attenuation with ECP control signal.  

2) ECP brake signal enjoys an advantage of rapid transmission. In a long train, because the idling braking time is greatly shortened, the advantage is more highlighted.  

3) The stopping distance in emergency brake for short train is short and the idling braking time is also short, therefore leaving not too much potential for improvement.

After application of distributed power control technology, the stopping distance for long trains and the in-train force are significantly reduced.

Compared with DP, train with ECP system has shorter stopping distance and smaller in-train force. In case of brake, the in-train force of ECP train is remarkably smaller than that of DP train. That's because for DP train, the brake signal still be transmitted through air within each sub consist, brake operation of different cars in sub consist is asynchronous. In case of ECP train, all the cars receive the braking command through train network so that they can apply brake almost synchronously.

<table>
<thead>
<tr>
<th>Scheme No.</th>
<th>Make-up</th>
<th>Initial brake speed (km/h)</th>
<th>Working mode</th>
<th>Stopping distance (m)</th>
<th>Improvement %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pure Air</td>
<td>DP</td>
</tr>
<tr>
<td>1</td>
<td>10,000 ton</td>
<td>90</td>
<td>Emergency brake</td>
<td>859</td>
<td>723</td>
</tr>
<tr>
<td>2</td>
<td>10,000 ton</td>
<td>70</td>
<td>Normal brake</td>
<td>1460</td>
<td>938</td>
</tr>
<tr>
<td>3</td>
<td>10,000 ton</td>
<td>30</td>
<td>Emergency brake</td>
<td>545</td>
<td>449</td>
</tr>
<tr>
<td>4</td>
<td>20,000 ton</td>
<td>90</td>
<td>Emergency brake</td>
<td>133</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>20,000 ton</td>
<td>70</td>
<td>Normal brake</td>
<td>1383</td>
<td>716</td>
</tr>
<tr>
<td>6</td>
<td>20,000 ton</td>
<td>30</td>
<td>Emergency brake</td>
<td>2134</td>
<td>889</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>70</td>
<td>Emergency brake</td>
<td>887</td>
<td>444</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>30</td>
<td>Emergency brake</td>
<td>224</td>
<td>98</td>
</tr>
</tbody>
</table>
Table 5 is the simulation result for draw-bar force

### Table 5 Simulation calculation result for coupling force

<table>
<thead>
<tr>
<th>Scheme No.</th>
<th>Make-up (ton)</th>
<th>Initial brake speed (km/h)</th>
<th>Working mode</th>
<th>Maximum draw-bar force (kN)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Pure Air</td>
<td>DP</td>
</tr>
<tr>
<td>1</td>
<td>10,000</td>
<td>90</td>
<td>Emergency brake</td>
<td>1089</td>
<td>458</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>70</td>
<td>Emergency brake</td>
<td>1132</td>
<td>496</td>
</tr>
<tr>
<td>4</td>
<td>20,000</td>
<td>30</td>
<td>Emergency brake</td>
<td>1236</td>
<td>587</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>90</td>
<td>Emergency brake</td>
<td>--</td>
<td>429</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>70</td>
<td>Emergency brake</td>
<td>--</td>
<td>456</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>30</td>
<td>Emergency brake</td>
<td>--</td>
<td>550</td>
</tr>
</tbody>
</table>

Table 6 provides simulation results for two different 20000t DP train configurations in case of emergency application.

### Table 6 simulation results for different 20000t DP train in case of emergency application

<table>
<thead>
<tr>
<th>Make-up</th>
<th>Initial brake speed (km/h)</th>
<th>Stopping distance (m)</th>
<th>Maximum draw-bar force (kN)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>2x10000t</td>
<td>90</td>
<td>778</td>
<td>1099</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>111</td>
<td>1239</td>
<td>162</td>
</tr>
<tr>
<td>4x5000t</td>
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<td>716</td>
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<td>155</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>98</td>
<td>550</td>
<td>155</td>
</tr>
</tbody>
</table>

While the 2 configuration is preferable from an operational perspective (easy to assemble), the 4x5000t configuration provides the benefits of shorter stopping distance and lower in-train forces.

7. Conclusion and prospect

(1) Simulation result and overseas experiment result show that, compared with conventional brake system, ECP enjoys the following advantages:

- Brake distance is shortened by 20% to 64%;
- Maximum brake force within the train is reduced to prevent rigid impact.

(2) Without relevant measures, it is dangerous to drive a 20,000-ton heavy-haul train and rigid impact will arise in emergency brake.

(3) Both DP and ECP technology can meet the requirement of operation 20,000 ton heavy-haul train. But the in-train force in case of brake of ECP train is remarkably smaller than that of DP train;

(4) The above calculation is done on straight and level lines, and slope situation is subject to further research.

Heavy-haul train experiment for power distribution control system is finished and analysis for experiment data is being done. Next step is to verify the models on the basis of experiment results.

For successful operation of 20000-ton heavy haul train, train handling is one of the key factors. The driving strategies currently used on DaQin railway have evolved over the years as a combination of initial training and adaptations developed by drivers by personal experiences. They apply to 10000t train running on DaQin railway. For 20000-ton train, they must be adapted to the new situation. Further study should be carried out through combing simulation and field experiences provided by drivers.

Bibliography


[5] Specification S-4200-00: PERFORMANCE REQUIREMENT FOR ELECTRONICALLY CONTROLLED PNEUMATIC (ECP) CABLE-BASED FREIGHT BRAKE SYSTEMS [S].