

# System integration and innovation of operating 20 kt combined heavy-haul train on Datong-Qinhuangdao line

Geng Zhixiu

(Ministry of Railways PRC, Beijing 100844, China)

---

**Abstract:** Datong-Qinhuangdao line, as the first electrified double-track heavy-haul line dedicated to coal transport in China, extends from Datong in the west, and reaches Qinhuangdao in the east, opened to traffic in December, 1992, totaling 653 km with the designed annual traffic volume of  $1 \times 10^8$  t. In order to meet the demands of national economic development, the transport capacity of the line must be enhanced greatly. Depending on independent innovation, MOR, for the first time in the world, realizes the integration between GSM-R and Locotrol, the integration between 800 MHz digital radio and Locotrol, and the integration between a single set of Locotrol and SS4 locomotive. Meanwhile, CR develops equipment portfolio for heavy-haul through combining 2 high power locomotives of HX<sub>D</sub> series (means harmony) with controllable EOT. Relying on integration and innovation, it succeeds in operating 20 kt-level combined heavy-haul train on Datong-Qinhuangdao line, which tripled the annual traffic volume of the line from  $1 \times 10^8$  t in 2002 to  $3 \times 10^8$  t in 2007.

**Key words:** China railways; Datong-Qinhuangdao line; 20 kt-level combined heavy-haul train; integration and innovation

## 1 Introduction

Datong-Qinhuangdao line, as the first electrified double-track heavy-haul line dedicated to coal transportation in China, extends from Hanjialing Station in Datong in the west and reaches Liucun South Station in Qinhuangdao in the east. The line opened in December 1992, with a total length of 653 km and designed annual traffic volume of  $1 \times 10^8$  t. Serving as the most important coal transportation corridor, Datong-Qinhuangdao line undertakes the coal transportation task for 6 major electric grids, 5 major power generation companies, more than 350 major power plants, 10 major steel mill corporations and over 6 000 enterprises for their industrial production, civil use and export purpose. That means nearly 10 % of the national output of mine coal, i. e. 20 % of railway coal traffic, relies on Datong-Qinhuangdao line. In order to relieve the tension status of national coal, electric power and oil supplies and transportation, connotation-oriented expanded reproduction must be relied on to expand transport capacity of the line to a large extent as soon as possible.

Ever since 2003, through scientific validation and system organization and relying on independent innova-

tion, MOR (the Ministry of Railways) succeeds in operating 20 kt combined heavy-haul trains on the line and increases traffic volume from  $1 \times 10^8$  t in 2002 to  $3 \times 10^8$  t in 2007, tripling original designed capacity of the line, which improves the transport capacity greatly, alleviates tense situation of outward coal transport in Shanxi Province, makes important contribution for sound growth of national economy, and indicates heavy-haul technologies of CR (China railways) reaching the world advanced level.

## 2 Technical validation of operating heavy-haul trains

### 2.1 Analysis on development tendency of world heavy-haul railways

Since the 1950s, thanks to its large capacity, high efficiency and low cost, heavy-haul system has drawn wide attention of different railways and got a rapid growth in countries such as U. S. , Canada, Brazil, Australia, South Africa, etc. , which have vast territories, abundant resources and where traffic volumes of bulk cargo like coal and iron ore take up large proportions.

In order to promote the development of heavy-haul in the world, in 1985, U. S. , Australia, China, Can-

---

Received 21 December 2007

ada and South Africa initiated the International Heavy Haul Association (IHHA), which now has nine permanent members<sup>[1]</sup>, i. e. Australia, Brazil, Canada, China, India, South Africa, Russia, Sweden, Norway and U. S.

Due to differences in operating conditions and technical equipment level, each country uses different operating modes and organizations of heavy-haul trains. There are three main modes<sup>[2]</sup>:

1) Unit heavy-haul train, featured with fixed formation, single bulk cargo and centralized traffic, makes turn-around journeys between loading and unloading points;

2) Combined heavy-haul train, being coupled by two trains or more, has locomotives distributed among the long haul train;

3) Mixed heavy-haul train, coupled with several different headed locomotives and with mixed formation.

At present, some countries including U. S., Canada, Brazil, Australia and South Africa are operating both unit heavy-haul trains and combined ones. In addition, South Africa also runs mixed heavy-haul trains, and Russia focuses on development of combined ones and super-long and super-load unit trains.

After 1980s, owing to wide application of modern high technologies including new materials, new techniques, computer control and IT on railways, technologies and equipment level of heavy-haul are improved continuously. Traction power tends to high-power AC (alternating current) drive; freight car develops towards heavy axle-load, and locomotive traction and braking towards synchronous control. In order to meet the requirements of axle load increase, new development is occurred in track structure<sup>[3]</sup>.

In terms of annual traffic volume, Victoria-Minas line in Brazil (898 km) fulfils  $1.3 \times 10^8$  t, Mpumalanga-Richards Bay line (580 km) in South Africa achieves  $1.05 \times 10^8$  t, Newman-Headland line (426 km) in Australia reaches  $1.09 \times 10^8$  t, and other heavy-haul lines in different countries averages below  $1 \times 10^8$  t.

## 2.2 Technical and economic analysis on operating heavy-haul trains on Datong-Qinhuangdao line

In order to quickly enhance the capacity to a large extent, MOR has organized a series of detailed technical and economic analysis and verification.

Trains speed, density and weight comprise the three factors of transport capacity; each of them could improve the capacity. In 2002, Datong-Qinhuangdao line reached the target of annual volume of  $1 \times 10^8$  t, with maximum running speed of 80 km/h, traffic den-

sity of 87 train/day and train weight of 5 ~ 6 kt.

As per railway capacity calculation formula (shown as in tons of goods transported):

$$G_{d,max} = A \frac{Q_{total}}{I} \quad (1)$$

$G_{d,max}$  is average daily maximum capacity in goods transport direction;  $Q_{total}$  is total traction weight of a train;  $I$  is headway of trains (reciprocal of train density);  $A$  is a constant related to factors including fixed performance time, effective availability of section, and train dead load/gross weight coefficient.

If the headway on Datong-Qinhuangdao line is cut from present 14 min to 10 min, transport capacity could be only improved by 40%. Transport capacity could be expanded to a limited extent through reducing headway and increasing operating density, however, the works of upgrading is huge due to constraints of signaling system, setting of blocking section, marshalling capability, loading and unloading capacities, etc.

To convert the formula into another one by train running speed that calculates transport capacity (indicated with tons of goods transported):

$$G_{d,max} = BQ_{total}f(v_{operating}) \quad (2)$$

$v_{operating}$  is train running speed;  $B$  is a constant related to factors including fixed performance time, effective availability of section, train dead load/gross weight coefficient, length of blocking section, total length of a train, etc.

If the train maximum running speed is increased from 80 km/h to 120 km/h, the transport capacity could only be improved maximum by 50% owing to the effect of starting and stopping time of trains, as well as performance time at stations. In addition, investment will be huge in consideration of many constraint factors such as locomotive horse power, car manufacturing configuration, track condition and setting of blocking section, etc.

A common way for railways to improve freight transport capacity is to increase train load for bulk cargo transport, which has advantages of less investment and remarkable improvement. Depending on multi-locomotive traction, advanced locomotives synchronous control technology and heavy-haul supporting technologies, train weight could be increased to 20 kt or above, which could expand capacity to a large extent. If traction load of trains is upgraded from 5 kt to 20 kt, the transport capacity could be tripled either by Eq. (1) or Eq. (2).

According to traffic forecast, the traffic demands of Datong-Qinhuangdao line will reach  $4 \times 10^8$  t/a during "The 11<sup>th</sup> Five-year Plan" period. In order to realize great improvement of transport capacity on the line

and meet traffic demands, under the condition of no construction of new lines, the capacity could only be expanded by increasing train weight. Once train weight is increased to 20 kt-level, dead load of each train will reach 16.8 kt, and annual traffic volume could reach  $4 \times 10^8$  t under the circumstances that 66 pairs of trains are operated everyday. Therefore, increasing train weight is the most economical and effective way to expand transport capacity.

### 2.3 Comparison and selection optimization of key technologies for operating heavy-haul trains

The key for operating 20 kt heavy-haul trains is to solve the major problem of many locomotives driving a long heavy train synchronously. For this purpose, MOR organizes technical personnel to carry out comprehensive investigation, feasibility studies, comparison and selection optimization.

At present, there are two technologies adopted to

solve the synchronous control problems. One is Locotrol that transmits command by radio, and another is ECP that transmits command through wire.

#### 2.3.1 Main characteristics of Locotrol

The system mainly provides remote control function among locomotives. And a leading locomotive controls remotely other locomotives distributed among a long haul train to make them in synchronized traction, braking or release conditions, which optimizes power distribution and braking control of the whole train, and accelerates braking and release propagation rates<sup>[4]</sup> ( Fig. 1 ).

#### 2.3.2 Main characteristics of ECP

ECP consists of control units on locomotives and each car and train network. Control information is transmitted through train network to make synchronous braking or release of cars, and minimize longitudinal force of the train.

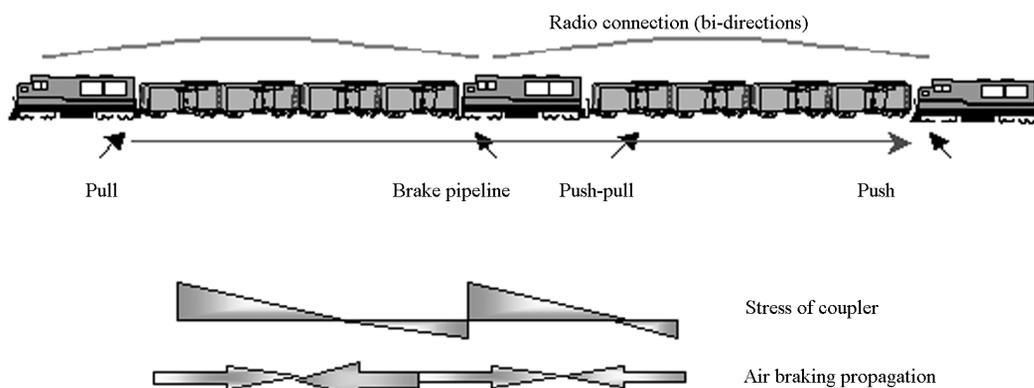


Fig. 1 Principle of Locotrol system

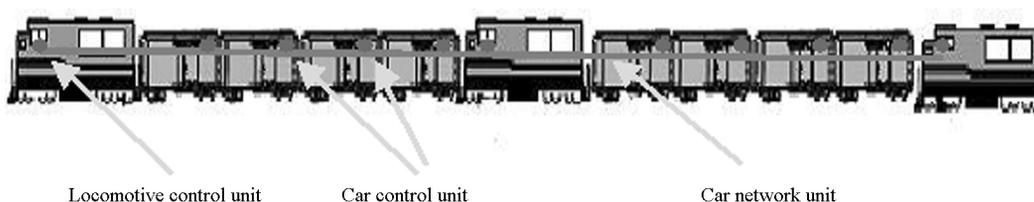


Fig. 2 System diagram of ECP

#### 2.3.3 Technical comparison and analysis of Locotrol and ECP

Locotrol system ensures synchronous working conditions of locomotives distributed in a long train, reduces longitudinal impact and force effectively, and shortens braking distance and braking time, thus making start and stoppage of a train more quickly and smoothly, and improving train running safety and effi-

ciency<sup>[5]</sup>. ECP uses electronically controlled braking system to realize synchronous working conditions of each car. Both technologies could meet technical requirements of operating 20 kt trains.

Compared with ECP, thanks to the application of synchronous radio control, Locotrol has traction power distributed on different positions of a train, boasting following characteristics: a. Simple configuration.

Train control system is centralized on locomotives, which reduces the workload of car refurbishment and cuts cost; b. Easy for traffic organization. Trains do not need inter-connection with wire, which facilitates formation coupling and uncoupling; c. Easy maintenance and management. The system is better suitable for operating characteristics of China Railways, and has the significance of wide application. However, reliable radio communication is indispensable for normal work of the system.

On the basis of detailed study on the experience of using Locotrol and ECP to operate heavy-haul trains in the U. S. and South Africa, as well as careful analysis on the specific situations of China and China Railways, it is concluded that Locotrol, featuring proven and reliable, has the value of wide application promotion in CR under the condition of guaranteeing normal work of radio communication. According to the suggestions made by the technical study tour team, MOR had decided to adopt Locotrol technology to realize technical innovation of operating 20 kt combined heavy-haul trains on Datong-Qinhuangdao line.

#### **2.4 Analysis on three key technical problems**

Datong-Qinhuangdao line, having lots of tunnels and curved sections, passes through many mountainous areas. There are 48 tunnels on the line totaling 65.8 km, of which the longest one is Jundushan Tunnel that extends 8.4 km and has two long steep grades in the running direction of loaded trains; one has length of 47 km and its average gradient is  $-8.2\%$ , and the other one has length of 50 km and its average gradient is  $-9.1\%$  and the maximum gradient is  $-12\%$ , known as the most difficult section on the line. To use Locotrol technology to operate 20 kt combined heavy-haul trains, three key technical problems must be solved.

##### **2.4.1 Reliability of railway communications in mountainous areas**

20 kt heavy-haul trains are driven by several locomotives equipped with Locotrol system, and the locomotive control command is sent from the leading locomotive to slave ones via radio. Thus, the synchronization of locomotives working is vital; non-synchronization will bring huge longitudinal force that threatens the safety of trains. Datong-Qinhuang line is mainly located in mountainous areas and has many tunnels, which are unfavorable for the transmission of radio. However, in order to transmit train control command, radio communication must be accurate and uninterrupted; and this raises higher requirements on the reliability of communications.

##### **2.4.2 Repeated cycle brake on long, steep descend-**

ing grade

Repeated cycle braking is a kind of continuous braking method, i. e., when a train approaches speed limitation, use step release air pressure brake and dynamic brake to make the train speed decrease to a certain level, then release, and use air braking next. The compressed air consumed in every air braking process must be compensated before the next braking, i. e., air charging is necessary and inadequate charging will have an influence on braking force of next braking.

In the two sections with long steep descending grades, comprehensive consideration must be given to factors including electric braking effort of locomotives, duration of train applying air brake, capabilities of air supply system on locomotives, the limit of longitudinal load of locomotives and cars, speed limit of the line, speed limit for air brake and release, etc. Then, it is necessary to prepare reasonable operation plan according to requirements of repeated cycle braking, so as to ensure combined heavy-haul trains running on long steep grades at speed in controllable range.

##### **2.4.3 Longitudinal impact of long trains**

A 20 kt level combined train has a length of 2 672 m and braking pipes of 3 000 m. Due to the constraints of propagation of air braking system, in service braking or emergency braking, enormous longitudinal force will be generated in case of inconsistency between braking forces in the front and rear parts of trains.

All factors for train longitudinal movement, including characteristics of locomotive traction and dynamic braking, characteristics of air braking system and coupler and draft gear device, and all running resistance could be simulated as per physical models. Subsequently, movement equations are established for each locomotive and wagon to get the longitudinal movement process of all locomotives and cars.

The analysis indicates that longitudinal force is related to synchronization of locomotives and cars braking, coupler slack, performance of draft gear and characteristics of braking system. Given the track condition and technical performance of locomotives and cars, relevant technical measures must be taken in order to operate 20 kt combined heavy-haul trains.

Thus, for operating 20 kt combined heavy-haul trains by using Locotrol on Datong-Qinhuangdao line, three key technical problems must be addressed on to determine the whole technical system and implement technical innovation.

#### **2.5 Whole technical system for combined heavy-haul trains**

Aiming at operating 20 kt combined heavy-haul trains on Datong-Qinhuangdao line, MOR comes up

with new ideas for innovation, i. e. , studies on the required traction demand, guarantees of reliable engineering work and systematic-rollout, which combine closely technical engineering upgrading with technical innovations and establishes the whole technical system for running combined heavy-haul trains(Fig. 3).

MOR had arranged to carry out over 60 research projects with main targets as tackling the three technical problems. Series of research studies, tests and technical upgrades are carried out in aspects of syn-

chronization control of locomotives, radio data transmission, traction, braking technologies, rolling stock heavy-haul technologies, infrastructure reinforcement technology, traction power supply reinforcement technology, heavy-haul traffic organization technology, optimized operational control of combined heavy-haul trains, comprehensive maintenance technology, etc. , therefore, technical innovation of operating 20 kt combined heavy-haul trains on Datong-Qinhuangdao line is conducted continuously.

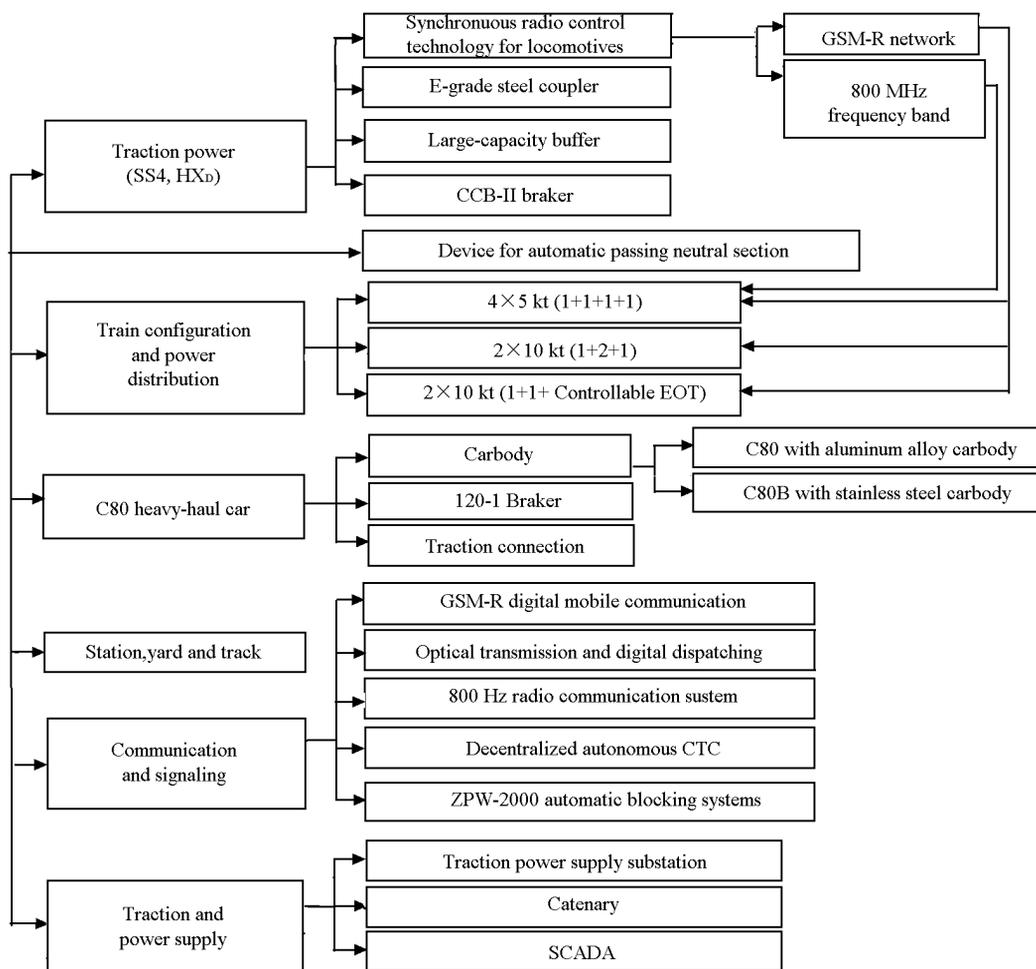


Fig. 3 Complete technical system of heavy-haul for 20 kt combined heavy-haul trains

### 3 Technology innovation of heavy-haul combined trains<sup>[6]</sup>

Since 2004, the Ministry of Railways has successively carried out technology innovation activities of operating 4 × 5 kt heavy-haul combined trains with 4 electric locomotives (Type SS4), operating 2 × 10 kt heavy-haul combined trains with 4 electric locomotives (Type SS4), and operating 2 × 10 kt heavy-haul com-

bined trains with 2 locomotives ( Type HXD ).

#### 3.1 The system integration of operating 4 × 5 kt heavy-haul combined trains with Type SS4 locomotive

The operation of 20 kt heavy-haul combined train with Locotrol technology mainly relies on the transmission of control command from the master locomotive to slave locomotives via radio communication. Therefore, the way of locomotive position arrangement of 20 kt combined train mainly lies on the transmission distance

of radio communication. The way of running 4 combined trains of 5 kt, namely the operation of  $4 \times 5$  kt heavy-haul combined trains, is defined on the basis of comprehensively analyzing the Datong-Qinhuangdao line and its traffic organization features, the reliable transmission distance of radio communication, and the power and brake system of locomotive and rolling stock.

In order to operate  $4 \times 5$  kt heavy-haul combined trains, four issues need to be addressed: first of all, the frequency for radio communication to meet the requirement of Datong-Qinhuangdao line needs to be selected. Secondly, the system integration of on-board radio communication equipment and Locotrol equipment need to be realized. Thirdly, Locotrol needs to be configured into Type SS4 electric locomotive and then integrated with the CCB II brake systems. The fourth is to organize comprehensive test verifications.

### 3.1.1 Determine to use 800 MHz radio communication frequency

The Locotrol systems in other countries usually work together with 450 MHz radio communication, which is applicable to plain terrain. In mountainous and tunnel area, the transmission distance of 450 MHz radio communication is only 650 m. Tests show that 450 MHz radio communication system is not applicable to condition of Datong-Qinhuangdao line. Aiming at the features and working mode of Locotrol system, especially the requirement of system for radio communication, we select China's 800 MHz radio communication system for Datong-Qinhuangdao line after the technical analysis on transmission distance of radio communication frequency under different terrain conditions. We also carry out the test of comparing the data trans-

mission features between 800 MHz and 450 MHz on the entire Datong-Qinhuangdao line. The test results show that both the bit error rate and the reliability of message retransmission of 800 MHz radio data communication are superior to that of 450 MHz radio data communication. The transmission distance of 800 MHz radio data communication in mountainous and tunnel areas can reach 790 m, and can meet the transmission requirement of 690 m for locomotives between each 5 kt trains.

### 3.1.2 Development of the system integration of on-board radio communication equipment and Locotrol equipment

The MOR organized to develop the prototype of 800 MHz radio data transmission equipment. After laboratory tests and joint debugging with Locotrol equipment, the mode of interface, data transmission protocol, and content of radio data transmission are determined. Besides, the antenna gain is improved, and the technology measures such as error correction encoding processing and repeated commission of data transmission are adopted.

A set of 800 MHz radio data transmission equipment RDTE-A is installed at the end A of SS4 locomotive, and connected to the CIOM interface unit of Locotrol system. A set of 800 MHz radio data transmission equipment RDTE-B is installed at the end B of locomotive, and connected to CIOM interface unit at the end A of locomotive by train through wire.

The radio data communication equipment is installed on all the 4 locomotives of the  $4 \times 5$  kt combined trains (Fig. 5).

The 4 sets of master locomotives combine the ways of broadcast and relay to transmit information.

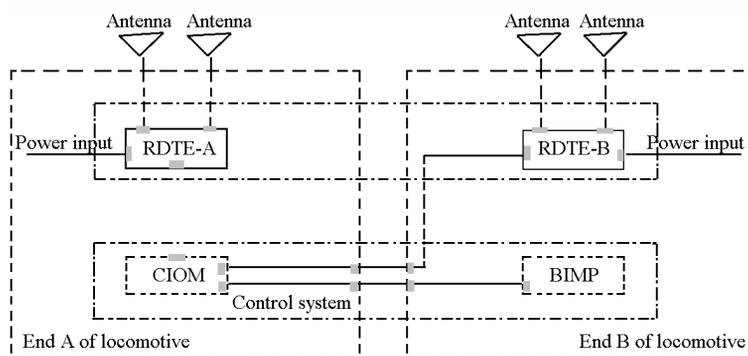
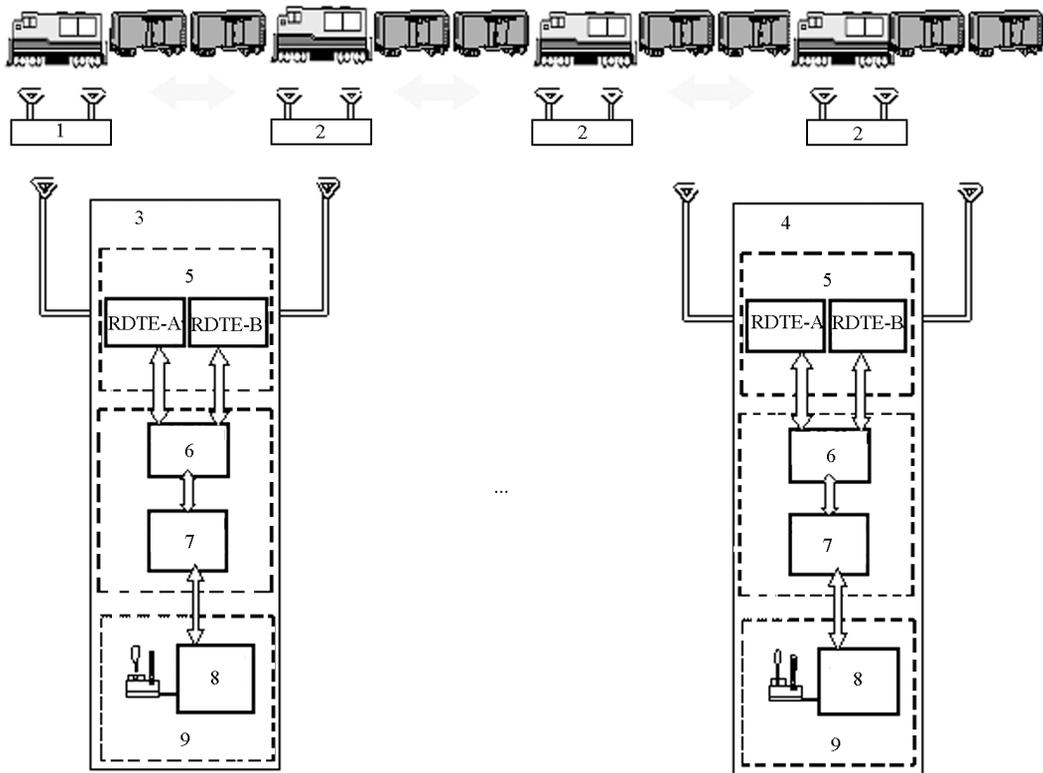


Fig. 4 The layout of locomotive equipped with 800 MHz radio data transmission equipment



1—Master locomotive cab radio data communication equipment; 2—Slave locomotive cab radio data communication equipment; 3—Master locomotive; 4—Slave locomotive; 5—Radio data communication; 6—Communication interface modular; 7—Locotrol control system; 8—Locomotive control system; 9—Locomotive operation control equipment

Fig. 5 The structure of 800 MHz radio data transmission system

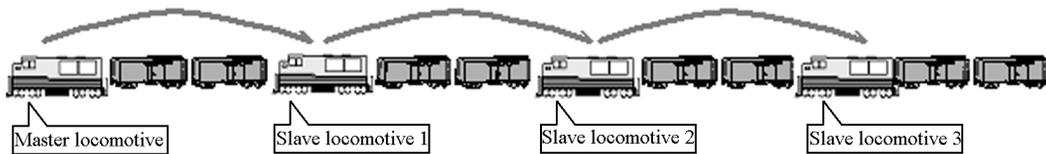


Fig. 6 Diagram of repeater

Through the integration of 800 MHz and Locotrol system, the real-time and reliable data radio transmission of the control command between the master locomotive and slave locomotives of 4 × 5 kt heavy-haul combined train is realized.

### 3.1.3 The technology integration of Locotrol and CCB II brake equipped on Type SS4 electric locomotive

After the studies and design, the overall solution of the technology integration of SS4 locomotive, Locotrol and CCB II brake is proposed, and the specifications and the synchronous operation control modes for electrical, pneumatic, and mechanical interfaces are determined. The cab radio control command, locomotive state and alarm message, locomotive safety interlocking and protection measures are developed and de-

signed, and the problems of arrangement and wiring of Locotrol and CCB II system equipment in locomotive as well as the electromagnetic interference and mechanical shock and impact prevention technology and techniques are solved. Through the studies on the optimized schemes, the decision is that the master locomotive uses a single set of Locotrol equipment to realize two-end synchronous operation. The test and verification showed that the system integration of SS4 locomotive, Locotrol, and CCB II brake as well as its accessory equipment is successful, and it meets the requirement of synchronous traction and brake by multiple locomotives.

### 3.1.4 Organize the comprehensive test and verification of 4 × 5 kt heavy-haul combined train

The Ministry of Railways organized to implement 2

phases of comprehensive tests of  $4 \times 5$  kt heavy-haul combined train. The 1<sup>st</sup> test phase lasted 2 months. On December 12, 2004, the trial operation of China's first 20 kt ( $4 \times 5$  kt) heavy-haul combined trains was successfully completed. During this phase, the integration of 800 MHz radio and Locotrol technology, and the integration of SS4 locomotive, Locotrol technology, and CCB II brake were verified. The 2<sup>nd</sup> phase of the comprehensive test lasted from July 7, 2005 to July 13, 2005 with the focus on the test and verification of SS4 locomotive modification scheme, the new-type C80 wagon (3 wagons form a group to use the traction bar, Type 120-4 brake, and high capacity rubber draft gear), and the locomotive automatically passing neutral-section equipment.

The two-phase comprehensive tests demonstrate that: a. the adoption of 800 MHz radio data transmission equipment on Datong-Qinhuangdao line can meet the need of the Locotrol application of 20 kt combined train combined in the way of  $4 \times 5$  kt. b. The braking distance of 20 kt combined train with Locotrol technology is basically equivalent to the braking distance under full service brake and grade emergency of a single 5 kt train. The adoption of Locotrol distributed power control system can efficiently accelerate the transmission speed of locomotive control command and shorten the air charging and discharging time of extra-long train. c. The longitudinal force of  $4 \times 5$  kt combined train is larger than that of single 5 kt train, and the largest longitudinal force appears in the middle of train, namely around the third locomotive. However, the safety requirement of train operation can be satisfied. After the installation of traction rod and 120-4 new-type air control valve, both the longitudinal impact and the

largest longitudinal force decrease remarkably in emergency brake and service brake. d. The equipment such as the modified SS4 electric locomotive and the automatic passing neutral-section equipment can meet the need of operating  $4 \times 5$  kt heavy-haul combined trains.

Through the technology development, system integration and comprehensive test verification, CR satisfies the requirement of operating  $4 \times 5$  kt heavy-haul combined trains with Locotrol system.

### 3.2 The system integration of operating $2 \times 10$ kt heavy-haul combined trains with Type SS4 locomotive

The operation of  $2 \times 10$  kt heavy-haul combined train on Datong-Qinhuangdao line accords with the transport features of Datong-Qinhuangdao line. Datong-Qinhuangdao line is a tree structure (Fig. 7).

At the coal mine deposits for Datong-Qinhuangdao line, there are about 80 long-term loading points with the capacity of 5 kt-or-above, of which, 35 loading points are of 10 kt level, and 9 loading points are of 20 kt level.

With the increase of traffic volume, the operation of  $2 \times 10$  kt heavy-haul combined train is conducive to the improvement of transport efficiency. Therefore, the Ministry of Railways decides to use the GSM-R communication transmission platform of Datong-Qinhuangdao line to carry out the test of  $2 \times 10$  kt heavy-haul combined train.

To operate  $2 \times 10$  kt heavy-haul combined trains, first of all, the system integration of GSM-R and Locotrol equipment needs to be realized. Secondly, the formation of  $2 \times 10$  kt heavy-haul combined train needs to be analyzed and calculated. Thirdly, the comprehensive test verification needs to be organized.

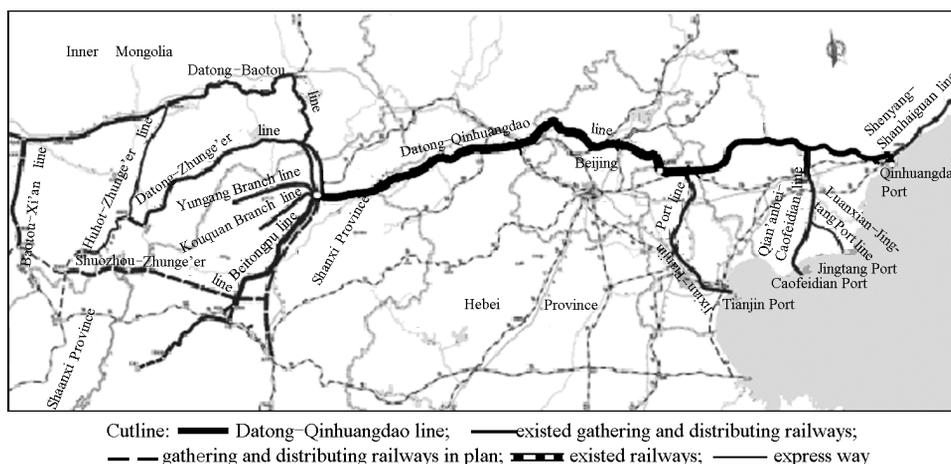


Fig. 7 Diagram of Datong-Qinhuangdao line

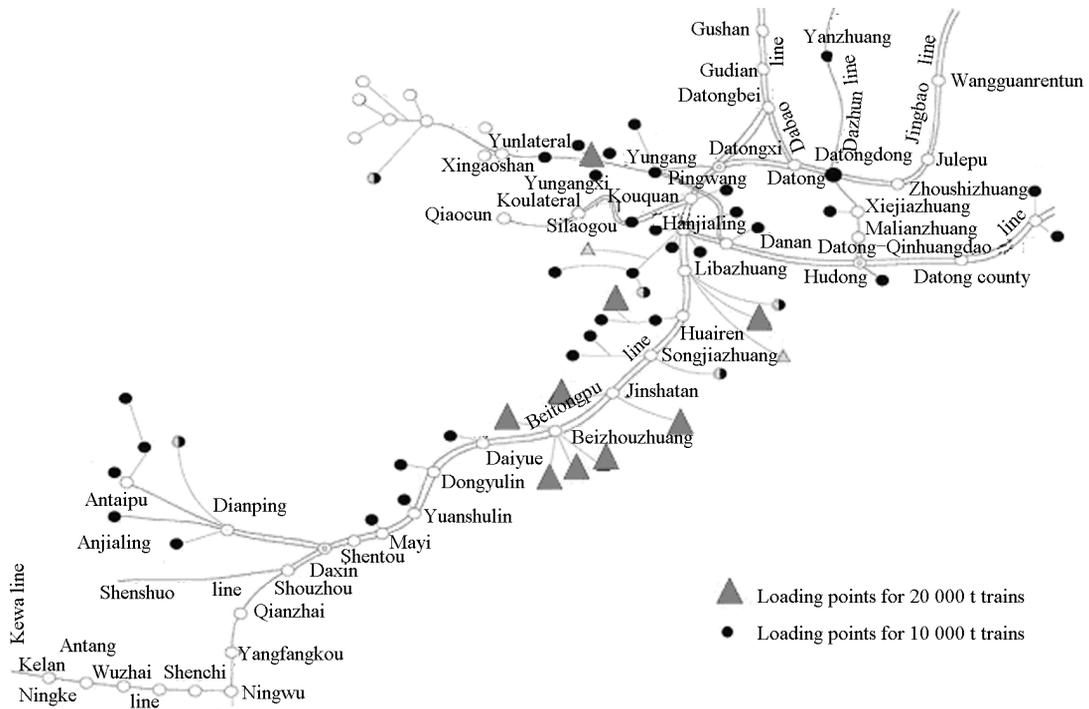


Fig. 8 Loading points above 10 kt on Datong-Qinhuangdao line

### 3.2.1 The system integration of GSM-R and Locotrol equipment

GSM-R is of network transmission from radio transmission to wire transmission, back to radio transmission again. Theoretically, GSM-R is not limited to transmission distance within network coverage. It can solve 800 MHz radio-transmission's problem of effective transmission distance limited to 790 m. Transmitting the information of Locotrol system on GSM-R network communication platform can satisfy the communication requirement of  $2 \times 10$  kt heavy-haul combined train.

The GSM-R communication system for Locotrol system consists of track side application node (AN), GSM-R network and GSM-R on-board communication unit (OCU). An on-board communication unit is installed on each locomotive and is linked to the track side application node through GSM-R network. The track side application nodes organize all the locomotive on-board communication units of a train into a group to realize the real-time data transmission between the master locomotive and slave locomotive<sup>[7]</sup>.

Therefore, combined with the practical conditions of GSM-R network, a set of track side application nodes linked to GSM-R network is established in Taiyuan; the on-board communication unit is developed; and *The Technology Standard on GSM-R Data Communication Equipment of Locotrol System* is formulated. Since the middle of April, 2005, many GSM-R

laboratory static tests and running tests have been carried out to verify the integration of GSM-R network and Locotrol as well as the automatic shift between GSM-R and 800 MHz. The test results show that, the real-time and reliable radio data transmission of the control command between the master locomotive and slave locomotive of  $2 \times 10$  kt heavy-haul combined train can be realized through the integration of GSM-R and Locotrol system<sup>[8]</sup>.

### 3.2.2 Determine the formation of $2 \times 10$ kt heavy-haul combined train

The heavy-haul combined train is formed in the way of  $2 \times 10$  kt. There are several options of locomotive arrangement, such as  $(1 + 2 + 1)$ ,  $(2 + 1 + 1)$  and  $(2 + 2)$ . The simulation calculation and comprehensive comparison selection are carried out to determine the formation of train. The main three plans are as follows.

Plan  $(2 + 2)$ :  $SS4 \times 2 + C80 \times 102 + SS4 \times 2 + C80 \times 102$

Plan  $(2 + 1 + 1)$ :  $SS4 \times 2 + C80 \times 102 + SS4 \times 1 + C80 \times 102 + SS4 \times 1$

Plan  $(1 + 2 + 1)$ :  $SS4 \times 1 + C80 \times 102 + SS4 \times 2 + C80 \times 102 + SS4 \times 1$

There is no big difference in dynamic brake and traction power among the three plans. According to the application conditions of Datong-Qinhuangdao line, the critical issues are the repeated brake application on long and steep down gradient and the generated longi-

tudinal force of train. Meanwhile, the requirement of traffic organization needs to be satisfied to the maximum possibility, and the traffic efficiency needs to be enhanced. Therefore, the K275 – K325 of Datong–Qinhuangdao line is chosen for the comparison analysis on the air charging capacity and longitudinal force of recycled brake on long and steep down gradient. The calculation results show that, the recycled brake frequencies of the three plans in K275 – K325 section all reach 11 times under the circumstances of not making most of dynamic brake. The shortest air recharging time lasts less than 2 minutes. As to Plan (1 + 2 + 1) or Plan (2 + 1 + 1), the air charging time can still fully satisfy the requirement because of the air charging function of end locomotive. As for Plan (2 + 2), because the air pressure from air recharging may not be enough for the train without end locomotive, the running safety of Plan (2 + 2) is inferior to that of Plan (1 + 2 + 1) or Plan (2 + 1 + 1). Besides, under the same operation conditions, for example, under the emergency brake situation of 80 km/h, the longitudinal force according to the simulation calculation of Plan (2 + 2) is 1 600 kN, which is 50 % or more larger than that of Plan (1 + 2 + 1) and Plan (2 + 1 + 1). While under the low-speed emergency brake situation of 40 km/h, the longitudinal force of Plan (2 + 2) approaches 2 000 kN, which has no sufficient safety consideration, therefore, Plan (2 + 2) is not suitable. As for the comparison between Plan (1 + 2 + 1) and Plan (2 + 1 + 1), Plan (1 + 2 + 1) is more conducive to the air charging of train brake and the traffic organization.

The research results show that Plan (1 + 2 + 1) acquires the advantage of high transport efficiency and strong controllability. It can enhance the traction and recycled braking performance of combined train, and effectively reduce the longitudinal force and impact of combined train. Besides, the end locomotive replacing EOT forms up a full loop for train integrity inspection, which is conducive to the safety of combined train, and is the best choice for the operation of 2 × 10 kt heavy-haul combined train on Datong–Qinhuangdao line.

### 3.2.3 Organize the comprehensive test verification

From November 2005 to January 2006, five phases of 2 × 10 kt comprehensive tests (204 wagons of C80) are carried out by adopting the (1 + 2 + 1) formation. To further tap potential and enhance capacity, 2 × 10.5 kt comprehensive tests (210 wagons of C80) were carried out in May 2006.

During the first and second phases of comprehensive test, the longitudinal dynamics and braking performance tests for both general-purpose C80 combined train and new-type C80 combined train were respec-

tively implemented.

During the third and fourth phases of comprehensive test, for the general-purpose C80 and new-type C80 combined trains, the tests of function and performance for the locomotive after being installed with CIOM module were implemented.

The fifth phase of comprehensive test mainly verified the train's longitudinal dynamics and braking performance after the number of wagons increased from 204 to 210.

The five phases of comprehensive tests show that:

- the adoption of GSM-R network can satisfy the application requirement of Locotrol system of 20 kt combined train in the formation of 2 × 10 kt.
- Based on the Locotrol locomotive radio synchronous control system, the adoption of (1 + 2 + 1) formation can effectively accelerate the transmission speed of train braking, remarkably shorten the air charging time of very long train, and reduce the train impact.
- The adoption of Locotrol technology on GSM-R network platform can satisfy the requirement of the recycle braking performance and emergency braking distance of 20 kt train on the long and steep grade.
- The adoption of Locotrol technology on GSM-R network can meet the need of the longitudinal dynamics of train. The maximum longitudinal force of the new-type C80 combined train is 41 % ~ 59 % lesser than that of the general-purpose C80 combined train.
- The longitudinal dynamics and braking performance of train with the number of wagon increasing from 204 to 210 can meet the operation need.

Through technology development, system integration, and comprehensive tests, China Railways has possessed the conditions of running 2 × 10 kt heavy-haul combined trains with Locotrol system.

### 3.3 System integration of operating 2 × 10 kt heavy-haul combined train with “HX<sub>D</sub>” locomotives

“HX<sub>D</sub>” locomotive, the powerful AC drive electric locomotive, is produced through re-innovation on the basis of introduction and absorption. The designed speed is 120 km/h, the traction power is 9 600 kW, the axle load is (23 + 2) t and the starting traction effort is 760 kN. The adoption of 2 “HX<sub>D</sub>” locomotives meets the need of the operation of 20 kt heavy-haul combined train and the reduction of the number of locomotives is beneficial to the transportation effectiveness and economic efficiency.

#### 3.3.1 Development of controllable EOT

For the purpose to cooperate with the HX<sub>D</sub> powerful locomotives adopted on Datong–Qinhuangdao line, the concept of an additional EOT at the end of the 20

kt heavy haul combined train was put forward to guarantee the safe and smooth operation of HX<sub>D</sub> 20 kt heavy haul combined train with (1 + 1) formation mode.

The controllable EOT mainly consists of control box, host and the data transmission channel. The main function of these equipment is to improve the braking performance of the whole train in accelerate the braking velocity, reducing the propagation impact and reducing the braking distance by way of the synchronous pressure release of EOT host and synchronous braking of the wagons at the end of train when the master locomotive of the heavy haul combined train starts the air braking pressure release.

The three key technological issues during the development of controllable EOT are the acquiring of locomotive braking information, the reliable transmission of braking information and the accurate response of the host at EOT. Regarding these three key technological issues of the controllable EOT used on Datong-Qinhuangdao line, the existing equipment resources are fully used combining with Locotrol system. The acquiring of the locomotive braking information is carried out by the locomotive operation monitoring device (LKJ) and then the information is transmitted to the control box at EOT by the communication interface. The same transmission mode as the communication module (OCU) in Locotrol system is applied for the reliable transmission of braking information data. In this way, the reliable transmission of system data is guaranteed taking advantage of the existing resources. Meanwhile, the time for research and development of the project and the cost for the whole equipment are reduced. The research and development of the EOT host computer is based on the current successful experience, which effectively solved the technological problems such as braking electromagnetic valve, reliability of communication module (TCU) and capacity of batteries.

On June 12, 2007, road test of controllable EOT was carried out with (1 + 1) combined 20 kt train on Datong-Qinhuangdao line and it was proved successful.

### 3.3.2 Organize the comprehensive test verification

From May to July, 2007, comprehensive and special tests were carried out on the traction of 20 kt heavy haul combined train with two powerful HX<sub>D</sub> electric locomotives and controllable EOT (end of train). The purpose of the comprehensive tests is to test the performance of locomotive radio synchronous system, service braking of 20 kt train, cycled braking on long and continuous slope, train starting on tangent track, longitudinal force of train, dynamic stress of locomotive and performance of controllable EOT. The purpose of the special tests is to test the emergency braking perform-

ance on 12 ‰ descending slope and the starting traction ability on 4 ‰ upgrade track. The test results of both the comprehensive and special tests proved that the traction of 20 kt heavy haul combined train with two powerful HX<sub>D</sub> electric locomotives and controllable EOT is safe and feasible.

At present, everyday six or seven 20 kt heavy-haul combined trains are operated with 2 high power HX<sub>D</sub> electric locomotives.

## 4 Research and development of major technical equipments and modification of corresponding technologies

In order to run 20 kt heavy-haul combined train, the Ministry of Railways systematically organized research and development of major technical equipments and also dedicated great efforts to modify corresponding technologies.

### 4.1 HX<sub>D</sub> high-power AC drive electric locomotive

The HX<sub>D</sub> high-power AC drive electric locomotive applies the most advanced AC drive technologies in the world; total eight drive axles with each axle of a power up to 1 200 kW; the electric braking is regenerative with high power; the power factor is close to 1 and the harmonic content is comparatively low; the mechanic strength of locomotive is designed depending on the requirements to haul 20 kt combined train; the running speed is up to 120 km/h with axle load of (23 + 2) t; the locomotive applied the computer network control system and the world leading CCB II brake technology as the braking system.

Under the organization of MOR and by means of re-innovation after introduction of foreign advanced technologies, total nine essential technologies, including locomotive assembling, network control, car body, braking system, drive device, traction converter, traction transformer, traction motor and bogie, are well acquainted and total ten major matching technologies such as the pantagraph are developed. The domestic-made HX<sub>D</sub> series high-power AC drive electric locomotives have been put into operation in batches.

### 4.2 The new type grade E steel coupler and large-capacity draft gear

Since the couplers and draft gears originally used on Datong-Qinhuangdao line can no longer meet the demands of 20 kt heavy-haul transportation, new type couplers and draft gears are developed accordingly.

The newly-developed grade E steel coupler as well as the coupler yoke has increased the intensity by 20 % comparing with that of the grade C steel coupler, which is strong enough to haul 20 kt vehicles. In addition, the grade E steel couplers and coupler yokes have

the same sizes as grade C steel couplers and yokes, so that they are more easily to be promoted and replaced.

The newly-developed large capacity QKX100 resilient rubber draft gear has capacity up to 100 kJ, which is two times of capacity of the original SS4 MT-2 draft gear. Its anti-impact speed is up to 10 km/h which greatly helps to reduce the longitudinal force and longitudinal acceleration of the locomotive. The new type plastic rubber draft gear is compatible with the existing draft gear therefore can replace each other in application.

#### **4.3 The new type C80 freight wagon and draw bar**

The new type aluminum alloy C80 and stainless steel C80B heavy-haul freight wagon with load of 80 t are developed. These two type wagons adopt under cross-braced bogie with axle-load of 25 t and swing motion bogie with axle-load of 25 t, featuring high running speed and stable dynamic performance. The wagon is known by its light tare weight and huge capacity, with load of single wagon respectively increased 6.7 % and 31.1 % in comparison with that of the C76 and C63A wagon. Its external dimension can also match the third and fourth generation tipper as well as other auxiliary equipments, which can realize continuous dumping operation without uncoupling.

The type RFC draw bar is developed as well, which adopts the grade E cast steel as material thus the strength is enhanced. The failure load are increased to more than 4 005 kN; the bar body applies case structure, whose tare weight decreases 280 kg comparing with the No. 16 and No. 17 couplers. The 20 kt heavy haul freight wagon reduced its tare weight by 38 t; the draw bar has a shoulder structure, with the two ends designed as spherical, which could better cater for the operation of the pusher and dumper. The use of the draw bar has effectively reduced the gap distance between wagons and the longitudinal impact thus has improved the dynamic performance of the vehicle.

#### **4.4 The Type 120-1 brake**

The Type 120-1 brake is developed on the basis of Type 120 brake to cope with the long and steep down gradient along Datong-Qinhuangdao line. It integrates the service brake function and meanwhile modifies the deficiencies of the local relief valve of the Type 120 brake and the emergency brake valve thus improves stability. The main functions of 120-1 brake has achieved world leading level therefore could be used together with the Locotrol series equipments to meet the demands of heavy haul transportation. Comparing with the Type 120 brake, the 150 wagons combined train reduces the total service braking time by over 30 %.

Test of the 20 kt heavy-haul combined train on Datong-Qinhuangdao line has proved that the 120-1 brake could effectively improve the cycle braking capacity. The decrease of longitudinal impulse also helps reduce the braking distance. In addition, the 120-1 brake can be used with the GK and 120 brakes, which are quite appropriate for the actual condition of Chinese freight transportation.

#### **4.5 The auto-passing neutral section**

Design of the auto-passing neutral section on Datong-Qinhuangdao line respectively takes three conditions into account: auto-passing neutral section of single locomotive, coupling locomotives and wireless distributed combined train. It also integrates the function of manual mode of passing the neutral section in special condition. Such a device is composed of onboard control device, receiver, light display and track side transponder. While running the 20 kt combined train by Locotrol system, the auto-passing neutral section will collaborate with the Locotrol system to cancel the synchronization of the master and slave locomotives. After automatically passing neutral section, the master and slave locomotives will automatically restore to the synchronous status. During the auto-passing phase separation, onboard devices will automatically control the traction and brake to increase or decrease relevant parameters to reduce the impact of the train. Via those dedicated anti-interference measures, the false-operation of automatic neutral section passing device due to the increase of traction current in heavy-haul train is eliminated<sup>[9]</sup>.

#### **4.6 The CTC system**

The CTC system of Datong-Qinhuangdao line integrates a series of modern technologies in traffic organization, computer, network communication and control system. Intelligent decentralized autonomous CTC principle is adopted to emphasize in the adjusted train running diagram, which takes both the train and shunting operation into account. While ensuring the automatic control of train route, shunting route control is also integrated to the system for centralized control, which avoids frequent handover of the control authority between desk controller and station operation staff thus improves the efficiency of the system and realizes high level automatization of the CTC system. It has integrated intelligent dispatching decision-making, real-time remote control, fails safety and information safety into one system, and represents high level stability; safety and modularization design in terms of hardware selection, structure design, software model, redundancy design and fail safety.

The application of the CTC system on Datong-Qin-

huangdao line well ensures the safety and high efficiency of the heavy-haul transportation. It could fully exert the capacity of the line so as to enhance the productivity and working condition.

#### **4.7 The 20 kt train simulation calculation and optimized control technologies**

The Datong-Qinhuangdao line has complicated surrounding geographical conditions, featuring numerous tunnels, bridges and curves. There are many long and steep downgrades along the line, with maximum down gradient of 12 ‰ and up gradient of 4 ‰. Such external conditions raises high requirements for the train control technologies of 20 kt heavy-haul transportation. Therefore, a series of technical measures are used to make complete computer simulation and also scientific and rational control regulations are stipulated, including regulations on startup, running on up-and-down grade, running in key section, running in restricted-speed section, control without communication access, control in bad weather so as to ensure the stable and safe running of the 20 kt heavy-haul trains.

#### **4.8 Reconstruction and upgrade of the auxiliary engineering on station and yard, traction and power supply, communication and signaling equipments**

In order to run the 20 kt heavy-haul combined train and enhance the transport capacity, a series of auxiliary engineering like station and yard, traction and power supply devices as well as communication and signaling equipments are reconstructed or upgraded.

##### **4.8.1 Reconstruction of the station and yard**

Efforts are made to reconstruct 11 stations and yards along the Datong-Qinhuangdao line, including Hudong, Yangyuan, Huashaoying, Zhulu, Yanqing, Chawu, Jinxian west, Zunhua north, Qian'an north, Houying (newly-constructed) and Liucun south. The arrival and departure tracks are effectively extended to 2 800 m or more. Within the covering range of the arrival and departure tracks, the gradient is no more than 1.5 ‰. The Hudong station dedicated to combination and Liucun south station dedicated to untwining are taken as emphasis for reconstruction. Three track series are newly constructed in Hudong station (each track series is composed of two arrival and departure tracks and one locomotive dedicated track), five track series are newly constructed in Liucun south station and four track series newly constructed in Qingchechang, which can fully meet the demands of the marshalling and operation of 20 kt combined train.

##### **4.8.2 Track and bridge technologies are enhanced**

To cope with the fast growth of the traffic volume of Datong-Qinhuangdao line, a series of technical re-

searches and tests are systematically carried out to ensure the operation of 20 kt combined train on Datong-Qinhuangdao line. According to the test results and maintenance requirements, tracks and bridges are enhanced during the comprehensive maintenance time slot. Rails and turnouts are replaced; Type III sleeper are used to replace the Type II sleeper; ballasts are cleaned and tamped; rails are grinded and tunnel failures are regulated. Twin beams no more than 20 m, 32 m simply supported beam and round middle and high piers are reconstructed and reinforced; the 8 m concrete beams are evaluated for its fatigue performance and service life. Those modifications have laid a sound foundation for Datong-Qinhuangdao line to realize safe production and an annual traffic volume of  $3 \times 10^8$  t.

##### **4.8.3 Upgrade of the traction power supply system and its matching technologies**

In order to meet the demands of the traction system on Datong-Qinhuangdao line, technical researches are carried out targeting the traction and power supply system for heavy haul and also the improvement plan is proposed to enhance the capacity. Five traction substations are newly constructed and 8 host transformers which are lack of capacity are replaced; Comprehensive Automation System for Traction power supply are established; a series of technical measures are applied, such as the adoption of supercharger and transformer, adjustable capacitor compensator, 150 mm<sup>2</sup> large-section contact wire and parallel overhead contact line. Pantograph-contact line relation is studied under the condition of multi-locomotive and multi-pantograph. The auxiliary parts are developed to match the large section contact wire. By means of the above technical measures and adoption of new technical equipments, the traction power supply capacity and reliability of the overhead contact line are enhanced so as to ensure the current-collecting of the 20 kt heavy-haul combined train.

##### **4.8.4 Technical modification of the communication and signaling equipments**

The GSM-R wireless bi-network system is improved. Mobile switching center is established in Taiyuan and meanwhile base-stations are established in Taiyuan and along the Datong-Qinhuangdao line. Optical fiber repeaters are set in the tunnel sections. Over 1 100 km multi-core optical fiber cable is laid.

The signaling equipments are modified as well with signals displayed via four-channel mode. ZPW-2000 A joint-less track circuit are adopted, and 15 stations and yards are connected by computer. Electrohydraulic switch machine is adopted for the turnout switch and Cab-signaling authorization is realized. Af-

ter calculation and test, the signaling equipments are proved to be qualified to cope with the interference of 200 A unbalanced traction current.

## 5 Innovations for running 20 kt heavy-haul trains on Datong-Qinhuangdao line

### 5.1 System integration and innovations

For the first time in the world, the Locotrol technology and GSM-R are integrated into one system to be successfully applied in the  $2 \times 10$  kt heavy-haul combined train. The development of Locotrol technology from point to point communication to systematic network communication was an effective solution for the limited communication distance between locomotives, indicating that heavy-haul technologies of China railways has made remarkable advance.

Two HX<sub>D</sub> high-power locomotives plus controllable "end of train" (EOT) are first used together for running the 20 kt heavy-haul combined train.

The 800 MHz digital radio is first used together with the Locotrol system worldwide in the  $4 \times 5$  kt heavy-haul combined train on Datong-Qinhuangdao line, which has extended the communication transmission distance from the original 650 m of 450 MHz to 790 m of 800 MHz, further expanding the application range of the Locotrol technology.

Integration of the Locotrol system and the SS4 locomotive makes it possible to synchronously operate and control both ends of the master locomotive. Modification of the 200 SS4 locomotives has saved a cost up to RMB 100 million yuan comparing with the original plan.

### 5.2 Innovations on technical equipment<sup>[10]</sup>

Firstly, the high-power AC drive electric locomotive technologies are imported and re-innovated after digestion and absorption so that some key technologies and major supporting technologies are systematically acquainted. Initial operation of the domestic-made HX<sub>D</sub> heavy-haul locomotive has filled up the gap of China railways in this regard.

Secondly, the newly-developed Type C80 heavy-haul wagon possessing a loading capacity of 80 t adopts the under cross-braced bogie with axle-load of 25 t (Type ZK6 bogie) and swing motion bogie with axle-load of 25 t (Type ZK5 bogie), featuring high running speed, stable dynamic performance, light car body and huge loading capacity. Currently the wagon has been put into operation in batches with two series respectively made of aluminum alloy and stainless steel.

Thirdly, major auxiliary equipments are correspondingly developed, such as the Type 120-4 brake valve, intermediate draw bar, Grade E steel coupler

and the large-capacity resilient rubber draft gear, which helps to reduce the longitudinal impact so as to enhance train safety.

Fourthly, application of the independently-developed locomotive automatic passing neutral device realizes automatic passing neutral of single locomotive, coupling locomotives and locomotive of wireless distributed combined train, thus ensuring safe and stable running of the heavy-haul combined train.

Finally, the decentralized autonomous CTC system is first used on coal heavy-haul line, which has effectively enhanced the carrying capacity, productivity and meanwhile improved the laboring condition.

### 5.3 Innovations on traffic organization

The traffic organization is greatly optimized. For the first time in the world, the  $2 \times 10$  kt heavy-haul combined train on Datong-Qinhuangdao line applies two marshalling modes respectively using 4 locomotives (1 + 2 + 1) and 2 HX<sub>D</sub> high-power AC drive electric locomotives (1 + 1 + controllable EOT). The two marshalling modes are designed targeting the characteristics of Datong-Qinhuangdao Line, having presented favorable effect like high transport efficiency, good braking performance, small longitudinal impact, high level safety and stability.

Integration of traffic gathering and distribution are realized. The operation of  $2 \times 10$  kt heavy-haul combined train has well met the needs of the total 35 10 kt and 9 20 kt car-loading stations, having effectively relieved the pressure of Hudong Station. Heavy-haul combined trains could be point-to-point operated among the nine 20 kt car-loading points, which fully exerts technical advantages and enhances the transport efficiency as well as benefit by a big margin.

## 6 Economic and social benefit

The operation of 20 kt heavy-haul combined trains has greatly increased the traffic volume of Datong-Qinhuangdao line and accomplished remarkable economic and social benefit.

### 6.1 The traffic volume is notably enhanced

From the year 2002 to 2007, the traffic volume of Datong-Qinhuangdao line was increased from  $1 \times 10^8$  t to  $3 \times 10^8$  t, a triple progress. From their first operation on March 28, 2006 to December 31, 2007, the 20 kt heavy-haul combined trains have completed an accumulated traffic volume of  $1.4 \times 10^8$  t, a number even more than the annual traffic volume of heavy-haul railways in other countries.

### 6.2 Transport revenues see remarkable increase

Datong-Qinhuangdao line has also seen great economic benefit, with its transport revenues soaring from

the RMB  $79 \times 10^8$  yuan in 2002 to  $172 \times 10^8$  yuan in 2007, an increase of 118 %.

The operation of 20 kt heavy-haul combined trains has greatly shortened the total turn-around time, cut down the operation cost, improved transport efficiency and brought tremendous benefit.

### 6.3 The social benefit is remarkable

Currently 30 heavy-haul combined trains of 20 kt are running on Datong-Qinhuangdao line per day, increasing the annual coal traffic volume by 84 Mt, which can generate extra electric power of  $1\,800 \times 10^8$  kW·h.

The successive operation of the HX<sub>D</sub> series high power AC drive electric locomotives as well as the increased running of 20 kt heavy-haul combined trains has laid a sound foundation for Datong-Qinhuangdao line to achieve the traffic volume of  $4 \times 10^8$  t by the end of “The 11<sup>th</sup> Five-year Plan” period.

In addition, the flourishing of Datong-Qinhuangdao line also helps to promote the development of some related fields. Great amount of modernized car-loading equipments is imported to coal production bases and meanwhile deep water docks together with car dumpers are newly established in ports. The railway artery has greatly increased the revenues of Shanxi Province, Shaanxi Province & the western area of Inner-Mongolia, boosted the development of Qinhuangdao Port, Jingtang Port and Tianjin Port, stimulated the booming of ocean going shipping market and promoted the revitalizing of regional economies.

## 7 Summary

The operation of 20 kt heavy-haul combined trains on Datong-Qinhuangdao line indicates that heavy-haul technologies of China railways has achieved a world

leading level, not only having laid a sound technical foundation for the potential soaring of traffic volume, but also having set a good example for other coal production bases to construct and develop their railway transport corridors. Datong-Qinhuangdao line has become a symbol project in heavy-haul transportation and capacity expansion of existing lines, a milestone in the development history of China railways as well.

## References

- [1] Qian Lixin. Worldwide railway heavy-haul transportation technologies[J]. Chinese Railways, 2007(6):49-53
- [2] Carlson F G, Round K C. Development and implementation of advanced brakes and improved suspension systems for the North American network[A]. Implementation of Heavy Haul Technology for Network Efficiency[C]. International Heavy Haul Association 2003 Specialist Technical Session, 2003, 5:1.1-4.10.
- [3] Dave van der Meulen. Railway globalization and heavy haul[A]. High Tech in Heavy Haul [C]. International Heavy Haul Association 2007 Specialist Technical Session, 2007. 329-338.
- [4] Küspert D, Kirchner D A. Locotrol RCL—an integrated locomotive system solution[J]. Railway Gazette International, 2005, 6: 36-39.
- [5] Zou Shijie. Railway heavy-haul transportation of the U. S. [J]. Foreign Rolling Stock, 2006, 5:1-5, 26.
- [6] Geng Zhixiu. System integration and innovations for operating 20 kt heavy-haul combined trains on Datong-Qinhuangdao line [J]. China Railways, 2007, 9: 25-29.
- [7] Song Gang. Composition and functions of the GSM-R system on Datong-Qinhuangdao line[J]. China Railways, 2007, 6: 45-48.
- [8] Gao Chunming, Ji Bin, Zhang Bo, et al. Study on the application of Locotrol technology in heavy-haul combined trains on Datong-Qinhuangdao line[J]. Electric Locomotives & Mass Transit Vehicles, 2006, 6: 5-7, 41.
- [9] Ning Tao, Li Ming. Improvements on the electric locomotive automatic passing neutral system on Datong-Qinhuangdao line [J]. Railway Locomotive & Car, 2007, 1: 40-42, 56.
- [10] Geng Zhixiu. Technological progress and achievements of China railways [J]. Railway Cooperation Organization Correspondence, 2005, 2:15-21.

## Author

Geng Zhixiu, born in 1952 and graduated from Lanzhou Railway University, has 6 papers published up to now. In recent years, he presided over the systematic integration and innovation of operating 20 kt combined heavy-haul trains on Datong-Qinhuangdao line, took charge of and participated in the scientific researches and tests regarding the 6<sup>th</sup> national speed-up campaign. Meanwhile, he organized the verification of significant technical issues, system integration and scientific researches relating to PDLs (passenger-dedicated lines). In addition, he also supervised the electrification project of Beijing-Shanghai railway line and led to settle a series of essential engineering and technical problems. Mr. Geng Zhixiu has been awarded the Achievement Award of the 8<sup>th</sup> Zhan Tianyou Railway Science and Technology Award and the Engineering Award of the 7<sup>th</sup> Guanhua Science and Technology Award. He can be reached by E-mail:miao999lei@sina.com