The Belt and Road Initiative
Vocational Textbooks for Rail Transit Education

Introduction to Multiple Unit Trains

动 车 组 概 论

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总　序

轨道交通职业教育“一带一路”系列教材是柳州铁道职业技术学院“十三五”规划期间重点建设项目之一。

该系列教材共包含 7 本教材，分别是《车站信号自动控制》（主编吴雄升、赵宁）、《电气化铁路接触网基础》（主编黄绘）、《动车组概论》（主编李英勇）、《复兴号动车组司机操作及整备》（主编谢小宁、蓝正新、覃海军）、《铁路信号基础设备维护》（主编陶汉卿、黄斌、姚明阳）、《铁路路基》（主编杨美玲）以及《铁路轨道工程》（主编李前豪、梁斌）。

译者认为，作为职业教育教材，该系列教材能够全面呈现铁路行业的新技术、新标准，并且将与铁路实际工作任务紧密对接的项目化教学法贯穿始终，适合于海外轨道类留学生、相关教师、铁路管理者学习、参考。

为推动职业教育国际化，助力中国高铁海外腾飞，编译团队决定先将其中 4 本教材编译成英文版本。本系列教材的编译是经过一年的艰辛和集体劳动的成果，译者都是有着本领域丰富的研究成果和教学经验的学者。4 本英文版译本教材均是 2020 年度广西职业教育教学改革研究项目《面向东盟的“三阶段、联盟制、标准化”高铁技能型人才培养模式研究与实践》的研究成果（项目编号 GXGZJG2020A049）。

《车站信号自动控制》的译者周澜教授有 30 年的职业教育从教经历，主要研究职业教育国际化推广，主持广西职业教育教学改革重点项目 3 项，获得省级教育教学成果一等奖 2 项，二等奖 3 项，三等奖 1 项。

《电气化铁路接触网基础》的译者卢雨松，自 2016 年进入柳州铁道职业技术学院国际教育学院工作以来，共参与了 7 期“东盟国家轨道交通职业教育师资培训班（泰国、印尼、马来西亚）”的接待、课程翻译等工作，积累了丰富的轨道交通领域翻译经验。

《动车组概论》的译者杨琳，商务英语专业毕业（英语专业八级），任柳州铁道职业技术学院国际教育学院院长，研究方向为职业教育国际化、留学生教育教学管理、跨文化交流。主持职业国际化项目研究 2 项，参与市厅级以上职业教育教学改革项目 6 项。

《复兴号动车组司机操作及整备》的译者罗敏，柳州铁道职业技术学院国际教育学院教师，工作期间积累了大量轨道交通领域的翻译经验。主要研究方向为高等职业教育国际化发展。

系列教材的编译过程中，译者们都投入了巨大的精力和时间，中文版教材的编写团队也是竭尽全力地给予译者专业知识的解答。在此，需要感谢四川语言桥信息技术有限公司和上海唐能翻译咨询有限公司提供了多位校审，为系列教材翻译的严谨性和准确性提出了宝贵意见。同时也要感谢西南交通大学出版社为教材能顺利出版给予的大力支持。要感谢的人很多，难以一一列举。

虽然译者和校审都尽心尽力，但因水平所限，译释不当之处在所难免，敬请各位读者和同仁批评指正。

轨道交通职业教育“一带一路”系列教材

英文版编译团队

2022 年 6 月

Preface

The compilation of "The Belt and Road Initiative Vocational Textbooks for Rail Transit Education" is one of the key construction projects of Liuzhou Railway Vocational Technical College during the "13th Five-Year Plan" period.

This series of textbooks includes 7 textbooks, namely: *Railway Station Signal Interlocking* (Chief Editor: Wu Xiongsheng, Zhao Ning), *Overhead Contact System Fundamentals of Electrified Railway* (Chief Editor: Huang Hui), *Introduction to Multiple Unit Trains* (Chief Editor: Li Yingyong), *Driver's Operation and Preparation on China Standard EMU* (Chief Editor: Xie Xiaoning, Lan Zhengxin, Qin Haijun), *Maintenance of Basic Railway Signaling Equipment* (Chief Editor: Tao Hanqing, Huang Bin, Yao Mingyang), *Railway Subgrade* (Chief Editor: Yang Meiling, and *Railway Track Works* (Chief Editor: Li Qianhao, Liang Bin).

The translators believe that this series of vocational textbooks can fully present the new technologies and new standards of the railway industry, integrating the project-based teaching method linked closely with the actual work tasks of railway engineering throughout the textbooks, and can be used by international undergraduates majoring in railway engineering, related teachers and railway managers for study and reference.

In order to promote the internationalization of vocational education and the overseas development of China's high-speed rail technologies, the compilation team decided to translate four of the textbooks into English version first. After the hard work and collaborative efforts in one year, the translation of these textbooks has been completed by translators who have achieved fruitful research results and accumulated rich teaching experience in the field. The English translations of all these four textbooks are the research results of *Research and Practice on the "Three-stage, Alliance-based and Standardized" High-speed Rail Skilled Talent Training Mode for ASEAN* (Project No.: GXGZJG2020A049), a Guangxi vocational education and teaching reform research project implemented in 2020.

Professor Zhou Lan, the translator of *Railway Station Signal Interlocking*, has 30 years of teaching experience in vocational education, mainly engaged in the study of the internationalization of vocational education. She has presided over 3 major projects of vocational education and teaching reform in Guangxi, and won 2 first prizes, 3 second prizes and 1 third prize of provincial education and teaching achievements.

Lu Yusong, the translator of *Overhead Contact System Fundamentals of Electrified Railway*, has participated in the work such as reception and course translation for 7 sessions of "Teacher Training for Rail Transit Vocational Education for ASEAN Countries (Thailand, Indonesia, Malaysia)" since he joined the School of International Education of Liuzhou Railway Vocational Technical College in 2016, and has accumulated rich experience in translation in the field of rail transit.

Yang Lin, the translator of the *Introduction to Multiple Unit Trains*, is the dean of the School of International Education of Liuzhou Railway Vocational Technical College, majored in business English (with the certificate of TEM-8) and mainly engaged in the research on the internationalization of vocational education, education and teaching management of international students, and cross-cultural communication. She has resided over 2 vocational education internationalization projects and participated in 6 vocational education and teaching reform projects above the municipal or department level.

Luo Min, the translator of *Driver's Operation and Preparation on China Standard EMU*, is a teacher of the School of International Education of Liuzhou Railway Vocational Technical College. She has also accumulated a lot of translation experience in the field of rail transit, mainly engaged in the research on the international development of higher vocational education.

In the process of the compilation and translation of this series of textbooks, all translators have spent much time and energy, and the compilation team of the

Chinese version of the textbooks has also made great efforts to explain relevant professional knowledge to the translators. Here, we would like to thank Sichuan Lan-bridge Information Technology Co., Ltd. and Talking China Language Services Co., Ltd. for providing a number of proofreaders who put forward valuable suggestions on the rigor and accuracy of the translation of this series of textbooks. At the same time, we would like to express our sincere gratitude for Southwest Jiaotong University Press for its strong supports. Sincere thanks to everyone who helped with the compilation and translation of these textbooks.

Any suggestions or comments on inadequacies found in these textbooks will be appreciated.

The Belt and Road Initiative Vocational Textbooks
for Rail Transit Education
English Version Compilation Team
June 2022

前　言

1964 年 10 月 1 日，运营速度达 210 km/h 的日本东海道新干线开通，标志着高速铁路的诞生。此后，世界各国争相规划和建设高速铁路，包括法国、德国、瑞典、意大利、西班牙、英国、韩国等已先后成功开行了高速列车，为经济发展做出了贡献。

我国的高速铁路始于 1994 年广州—深圳准高速铁路的建设成功并投入运营。截至 2018 年年底，我国铁路营业总里程达到 13.1 万千米，居世界首位，其中高速铁路营运里程数为 2.9 万千米。到 2020 年，我国高铁里程数有望超过 3 万千米，居世界第一位，成为世界上高速铁路发展最快、系统技术最全、集成能力最强、运营里程最长、运行速度最高、在建规模最大的国家。由此我国形成了具有自主知识产权的高速铁路技术与装备系统，成为中国装备制造“走出去”的一张亮丽的名片。

作为铁路运输装备的高速动车组，涉及系统集成技术、车体技术、转向架技术、制动技术、牵引传动技术、自动控制技术、网络与信息技术等是高新技术的综合应用和具体体现。目前，在打造中国品牌高速列车的过程中，铁路行业尤其与动车组相关的各工种人员也迫切需要了解一定的动车组知识。本书主要介绍动车组技术相关方面的知识，使读者全面系统地了解高速铁路发展历史和高速动车组及其关键技术，为其他课程的学习打下基础。全书共分 7 章：第 1 章概论，介绍世界主要国家高速铁路的发展、国内外主要国家的高速列车、动车组组成及其关键技术；第 2 章动车组车体技术，重点介绍动车组车体结构的空气动力学设计、车体轻量化设计、车体密封和隔声技术；第 3 章动车组转向架，重点介绍动车组转向架的技术特点、高速转向架应具备的性能、国外主要国家采用的动车组转向架；第 4 章动车组车端连接装置，重点介绍动车组车端连接装置的组成和作用、车钩缓冲装置作用与结构、风挡结构；第 5 章动车组制动系统，重点介绍动车组制动系统的基本组成、动车组电制动系统、动车组空气制动系统和制动控制系统；第 6 章动车组牵引传动系统，重点介绍动车组牵引传动方式，动车组牵引特性、牵引传动系统的组成、牵引传动控制功能；第 7 章国产动车组技术，重点介绍 4 种类型的动车组组成及主要设备等，并简要介绍 CRH380 系列动车组和 CR400 系列动车组的相关知识。本书可作为铁路高职院校相关铁路专业学生的教材和现场职工了解动车组知识的基础读物。

本书由柳州铁道职业技术学院李英勇任主编，南宁车辆段马维聪任主审，柳州铁道职业技术学院叶燕任副主编。具体编写分工如下：第 1 章由叶燕编写，第 2 章由韦宏思编写，第 3 章由伍志丹编写，第 4 章由黄聪编写，第 5 章由李英勇编写，第 6 章由欧红波编写，第 7 章由蒋婷、师光洲编写；参与书稿讨论的还有黄乾兴等老师。

本书在编写过程中参考了相关行业文献、专家著作以及国内外同类专业教材，在此表示衷心感谢。

由于编者水平所限，加之时间仓促，书中难免有疏漏之处，恳请读者批评指正。

编　者

2019 年 4 月

Foreword

On October 1, 1964, the Tokaido Shinkansen with the operating speed of 210 km/h was put into operation in Japan, marking the birth of the high-speed railway. Since then, many countries around the world, including France, Germany, Sweden, Italy, Spain, the United Kingdom, and South Korea, have rushed to plan and build high-speed railways and successfully put high-speed trains into operation, which has made important contributions to their economic development.

The construction of high-speed railways in China was started in 1994 when the Guangzhou-Shenzhen Quasi-High Speed Railway was successfully constructed and put into operation. By the end of 2018, the total railway operating mileage in China had reached 131,000 km, ranking the first in the whole world, including the high-speed railway operating mileage of 29,000 km. In 2020, the total high-speed railway operating mileage in China is expected to exceed 30,000 km and will still rank the first in the world. China will become a country with the fastest development of high-speed railways, the most complete system technologies and the strongest integration capabilities for high-speed railways, the longest high-speed railway operating mileage, the highest railway operating speed, and the largest scale of high-speed railways under construction in the world. A high-speed railway technology and equipment system with independent intellectual property rights has been established in China and has become a brilliant business card for Chinese equipment manufacturing industry to "go out".

As railway transport equipment, the high-speed multiple unit trains involve system integration technology, car body technology, bogie technology, braking technology, traction drive technology, automatic control technology, and network and information technology. It is the comprehensive application and concrete embodiment of these high and new technologies. At present, in the process of building Chinese brands of high-speed trains, the personnel of railway industry, especially workers engaged in various types of work related to multiple unit trains, also urgently need to know certain knowledge about multiple unit trains. This book introduces mainly the knowledge about multiple unit train technologies, so that readers can comprehensively and systematically understand the development history of high-speed railways,high-speed multiple unit trains and relevant key technologies, laying the foundation for the study of other courses. The book consists of 7 chapters, including:

Chapter 1 - Introduction; the development of high-speed railways in major countries in the world, the high-speed trains and the composition and key technologies of multiple unit trains at home and abroad are introduced in this chapter.

Chapter 2 - Technologies for the Car Body of Multiple Unit Trains; the focus of this chapter is laid on the aerodynamic design and lightweight design of the car body structure and the technologies for car body sealing and sound insulation.

Chapter 3 - Bogie of Multiple Unit Trains; the focus of this chapter is laid on the technical characteristics of the bogie of multiple unit trains, the required performance of the high-speed bogie, and the bogies adopted by major foreign countries for multiple unit trains.

Chapter 4 - Car End Coupling Devices of Multiple Unit Trains; the focus of this chapter is laid on the composition and function of the car end coupling devices of multiple unit trains, the function and structure of the coupler and draft gear, and the vestibule diaphragm structure.

Chapter 5 - Brake System of Multiple Unit Trains; the focus of this chapter is laid on the basic composition of the brake system, the electrical brake system, the air brake system, and the brake control system of multiple unit trains.

Chapter 6 - Traction Drive System of Multiple Unit Trains; the focus of this chapter is laid on the traction drive mode, tractive characteristics, composition of the traction drive system, and traction drive control function of multiple unit trains.

Chapter 7 - Technologies for Multiple Unit Trains Manufactured in China; the focus of this chapter is laid on the composition and main equipment of 4 main types of

EMUs and relevant knowledge about CRH380 series EMUs and CR400 series EMUs. This book can be used as a textbook for students majoring in railway in higher vocational colleges and a basic reading for on-site employees to understand the knowledge about multiple unit trains.

Li Yingyong from Liuzhou Railway Vocational Technical College serves as the chief editor of the book; Ma Weicong from Nanning Rolling Stock Depot serves as the chief reviewer of the book; Ye Yan from Liuzhou Railway Vocational Technical College serves as the associate editor of the book. During the preparation of the book, the specific division of work is as follows: Chapter 1 was prepared by Ye Yan, Chapter 2 by Wei Hongsi, Chapter 3 by Wu Zhidan, Chapter 4 by Huang Cong, Chapter 5 by Li Yingyong, Chapter 6 by Ou Hongbo, and Chapter 7 by Jiang Ting and Shi Guangzhou; Huang Qianxing and other teachers also participated in the discussion on the manuscript.

When the book was prepared, reference was made to relevant industry literatures, expert works, and similar professional teaching materials at home and abroad. Heartfelt thanks are hereby expressed.

Due to the limitations of the editor's level and the hasty time, insufficiencies may exist inevitably in the book. Please point out mistakes so that they can be corrected.

Editor

April 2019

Contents

Chapter 1

Introduction

High-speed railway is the integration of high and new technologies in today's world, the crystallization of human civilization and the symbol of railway modernization. It can reflect not only the technological progress of a country in such fields as railway traction power, line structure, technologies for cars, train operation control, and transport organization and operation management, but also the technological and industrial level of a country. Since its birth, the high-speed railway has brought about remarkable economic and social benefits in economically developed and densely populated regions.

1.1 Overview of High-speed Railway

1.1.1 Definition of High-speed Railway

The high-speed railway (HSR) is defined broadly, involving many systems in the field of high-speed railway. The International Union of Railways (UIC) defines the HSR lines as new lines with a design speed of 250 km/h or higher, or existing lines with an operating speed of 200 km/h or higher after reconstruction.

In China, the HSR lines are defined as the new railway lines designed for the operation of multiple unit trains at a speed of 250 km/h or higher, and with an initial operating speed not less than 200 km/h, including those new railway lines with a reserved operating speed of 250 km/h or higher.

The operating speed of trains is generally classified as follows:

(1) Ordinary speed: Maximum operating speed 100 to 160 km/h;

(2) Fast: Maximum operating speed 160 to 200 km/h;

(3) High speed: Maximum operating speed 200 to 400 km/h;

(4) Super-fast: Maximum operating speed ⩾400 km/h

1.1.2 High and New Technologies for HSR

1. HSR Lines

HSR lines are the foundation for HSR. New technologies involved in the construction of HSR lines include:

(1) High-standard plan and profile design;

(2) New structure of HSR ballastless track;

(3) HSR turnouts;

(4) HSR subgrade and approach embankment;

(5) HSR bridges;

(6) HSR tunnels;

(7) HSR traction power supply system, etc.

2. High-speed Trains

The high-speed train is the core of the new technologies for HSR. It involves the following new technologies:

(1) Excellent aerodynamic shape design;

(2) Lightweight design of car body structure;

(3) High-performance bogie;

(4) Compound braking;

(5) Tight-lock coupler and draft gear;

(6) AC drive;

(7) Automatic train control and fault diagnosis;

(8) Car sealing, sound insulation and feces collection and treatment;

(9) High-performance pantograph;

(10) Pendulum car body, etc.

3. Safe Operation Management System of HSR

The safe operation management system is the “nerve center” of HSR and involves the following new technologies:

(1) Automatic Train Control (ATC);

(2) Communication-based Train Control – moving block System (CTCS);

(3) Centralized Traffic Control (CTC) Center;

(4) HSR line monitoring and diagnosis system;

(5) Natural disaster alarm system (earthquake, debris flow, typhoon, snow, storm, etc.);

(6) Inspection and repair of high-speed trains based on time or running kilometers (inspection and repair of the whole multiple unit train with car bodies jacked up);

(7) HSR passenger service system (safety, comfort, punctuality, and convenience), etc.

1.1.3 Characteristics of HSR Passenger Transport

HSR has become popular and developed rapidly in many countries around the world, which is because HSR not only overcomes the disadvantage of low speed of ordinary railways, but also has the following characteristics compared with automobile transportation on highways and medium- and long-distance air transportation:

1. Reduced Passenger Transport Time

Fast speed is the core of HSR technologies and also the main technical advantage of HSR. So far, HSR has become the fastest transportation mode with the longest land transportation distance. At present, the operating speed of high-speed trains has reached 350 km/h, which is close to three times the speed of cars running on highways, reaching 1/3 of the speed of jet aircraft and 1/2 of the speed of short-distance aircraft. Therefore, HSR passenger transport can always show the advantage of saving total travel time when the transport distance ranges from 100 to 1 000 km.

2. Good Safety Performance

Safety is the primary consideration for people to choose a mode of transportation. Since HSR is operated in a fully enclosed mode with automatic operation control, and has a comprehensive safety guarantee system, its safety performance is unmatched by any other transportation mode. According to relevant statistics on the transportation of various countries, the ratio of accident rates (the number of casualties per million person-km of railway, highway and civil aviation transport is 1∶24∶0.8. HSRs in Japan have set a record of 45 consecutive years of safe operation without train overturning or passenger fatality.

3. High Punctuality Rate

According to the operation situation of high-speed railways in major countries, the train operation has generally a high punctuality rate, and the probability that the delay time is less than 5 minutes is higher than 90%, as shown in Table1.1. Among them, the average delay time of high-speed trains in France is 30 s; in the case of high traffic density, the delay time of 92.5% of the high-speed trains in Japan can still be kept to be no more than 1 min; the operator of AVE high-speed trains in Spain promises to refund all fare if the delay time is more than 5 min.

Table 1.1 Punctuality Rates of HSRs in Various Countries

Delay Time/min	≤1	≤3	≤5	≤10
Japan	92.5%	98.1%	98.5%	99.1%
France		90%		
Germany			90%	

4. High Transport Capacity

According to the statistics, almost all HSRs in various countries can meet the requirement for the minimum headway of 4 min. Each train on the Tokaido Shinkansen in Japan can carry 1 200 to 1 300 passengers. The departure interval during peak hours is 3.5 min, and the average number of departures is 11 per hour. For the 2.5-hour journey between Tokyo and Osaka, the annual average passenger throughput is up to 120 million person-time. By contrast, the annual average one-way transport capacity of a 4-lane highway is about 87 million persons. At present, the largest aircraft can carry 300 to 400 passengers; for flights between two places, the passenger transport capacity will be only 6 000 to 8 000 passengers if calculated according to 20 one-way flights per day.

5. All-weather Operation

HSR adopts a fully enclosed structure, with automatic control system. If there is no trackside signal, the driver can also ensure safe train operation relying on train-borne signaling, which will generally not be affected by weather changes. Even under severe natural disaster conditions, decelerated train operation can also be maintained. HSR transportation will not be as sensitive to heavy fog, heavy rain, heavy snow, thunder and lightning, and windy weather as road and air transportation. The HSR safety guarantee system can not only guarantee the safe operation of high-speed trains but also give full play to the advantage of all-weather railway transportation.

6. Low Energy Consumption

According to relevant statistics, the average energy consumption per kilometer per person of various transportation means is: 571.2 J for high-speed railways, 583.8 J for buses (1.02 times that of high-speed railways), 3,309.6 J for cars (5.79 times that of high-speed railways), and 2,998.8 J for airplanes (5.25 times that of high-speed railways). The energy consumption (per kilometer per person) ratio of high-speed railways, cars, and airplanes is 1∶5.79∶5.25. In addition, cars and airplanes mainly consume non-renewable primary energy – gasoline or diesel, while HSRs consume mainly secondary energy – electricity. With the development of new energy sources such as hydropower, solar energy, wind energy, and nuclear power, the advantages of HSRs in terms of energy will become more prominent. This is also one of the reasons why countries in the world choose to develop HSRs in the current situation of petroleum energy shortage.

7. Low Environmental Pollution

Environmental protection is now a global pressing issue concerning the survival of mankind. Transportation is closely related to environmental issues. At present, the pollution of transportation to the environment includes mainly exhaust gas and noise. According to statistics, the converted emissions of hazardous substances such as carbon monoxide of various transportation means are 0.109 kg/(person-km) for railways, 0.902 kg/(person-km) for highways, and 635 kg/(person-km) for airplanes. In terms of noise pollution, according to the calculations made by Japanese researchers, if the noise generated by the air transportation per kilometer per person is calculated as 1, the noise generated by cars and buses will be 1 and 0.2 respectively, while the noise generated by HSRs will be only 0.1. It can be seen from the above data that in modern transportation, the environmental pollution of HSR is significantly lower than that of air and automobile transportation.

8. Less Land Occupation

The width of the double-track railway is 13.7 m, while the width of a 4-lane highway is 26 m. The land occupation for the unit capacity of HSR is only about 1/3 of that of the highway. Although the air route of the airplane does not occupy land, a large airport shall be provided with runways, taxiways, aprons, terminal buildings, and other facilities. It will occupy a large area which is equivalent to the land area occupied by 1,000 km double-track railway. Since there must be at least 2 to 3 large airports for 1,000 km air route, the total land occupation of the airports will be 2 to 3 times that of 1,000 km double-track railway.

9. High Comfort Level

With the continuous improvement of people's material standard of living, travel comfort has become one of the important considerations for people to choose transportation means. The HSR lines are smooth and stable, and the trains can run steadily. The headway of trains can be designed according to the minimum of 3 min. Passengers can get on the train at any time without waiting for a long time. The space occupied by passengers on a train is much larger than that on a car or an airplane. The wide seats, comfortable ride, and freedom of movement on high-speed trains are incomparable; the high-speed trains can even provide conditions for conference, entertainment and sightseeing.

10. Good Benefits

The huge economic losses caused by the traffic jams and accidents on highways have become a worldwide problem. The annual costs of the European Community countries for dealing with highway congestion and traffic accidents account for 2.9% and 2.5% of their Gross National Product (GNP), respectively. In this case, the direct economic benefits of building HSRs are very obvious. According to statistics, the Tokaido Shinkansen in Japan was put into operation in 1964, and become profitable from 1966. It took only 7 years to recover all the investment for the line in 1971. Since 1985, the annual net profit of the line has reached JPY 200 billion (JPY 1 ≈ CNY 0.06).

The TGV southeast line in France was put into operation in 1983, and became profitable from 1984. After 10 years of operation, all investment for the line was recovered. In France, the benefits brought about by a high-speed railway are three times that of a 6-lane highway. In addition, the shortened travel time, the accelerated economic development along the HSR line, and the further development of the city where the station is located will all bring about huge economic benefits. At the same time, the high-speed railway also plays a huge role in promoting the development of the national economy and improving the comprehensive scientific and technological level of the country.

1.1.4 Characteristics of HSR Lines

High smoothness is the biggest difference between HSR lines and ordinary railway lines. In order to ensure that high-speed trains can operate safely, smoothly and uninterruptedly at the specified maximum speed, it is required that the spatial curves of HSR lines are smooth, and all components of subgrade, track and bridge are solid and stable, with high precision.

1. Standards for HSR Lines

1) Superelevation of outer rail on curve

When a train is running on a curve section, both the train and the passengers are subject to a centrifugal force. The centrifugal force not only increases the wheel-rail interaction force between the train and the track, but also affects the passengers' riding comfort. In order to reduce the centrifugal force experienced by passengers and the interaction force between the wheel and rail when the train is running on a curve section, superelevation will be set generally for the curve section, that is, the outer rail of the curve section will be raised while the height of the inner rail will remain unchanged.

The superelevation of the outer rail on curve is related to the curve radius and the average speed of the train. The maximum superelevation shall be selected so that the train will not be overturned when stopping on the curve and encountering strong winds, and the unbalanced centrifugal acceleration generated for the trains of different speeds will not be too high.

At present, except the Tokaido Shinkansen in Japan which has the maximum superelevation of 200 mm, the maximum superelevation of all other lines in Japan and HSR lines in other countries is 180 mm.

2) Minimum curve radius

The minimum curve radius of HSR lines in several major countries varies according to geographical conditions. See Table1.2 for details.

Table 1.2 Minimum Curve Radius of HSR Lines in Several Major Countries (Unit: m)

France		Germany	Italy	Japan			
TGV Southeast Line	TGV Atlantique			Tokaido	Sanyo	Tohoku	Joetsu
4,000(3,200)	6,000(4,000)	7,000(5,100)	3,000	2,500	4,000	4,000	4,000

The minimum curve radius of the HSRs with a design speed of 350 km/h in China is 7,000 m, and the minimum curve radius in special difficult sections can be 5,500 m. See Table 1.3 for details.

Table 1.3 Minimum Curve Radius of HSR Line Sections in China

Design Running Speed for the Section/(km/h)		Minimum Curve Radius/m	
200	Passenger dedicated railway	Normal	2,200
		Difficult	2,000
250	Ballasted track	Normal	3,500
		Difficult	3,000
	Ballastless track	Normal	3,200
		Difficult	2,800
300	Ballasted track	Normal	5,000
		Difficult	4,500
	Ballastless track	Normal	5,000
		Difficult	4,000
350	Ballasted track	Normal	7,000
		Difficult	6,000
	Ballastless track	Normal	7,000
		Difficult	5,500

3) Transition curve

In order to ensure safe operation of the train and safe, smooth and comfortable transition from a straight section to a circular curve or a circular curve to a straight section, and to avoid the sudden increase or elimination of the centrifugal force, it is necessary to set a transition curve with gradually changed radius of curvature between the straight section and the circular curve, as shown in Figure 1.1.

The alignment of the transition curve shall be as simple as possible and shall be convenient for rail laying and maintenance. The transition curve shall be as short as possible to reduce construction work quantity and investment cost; its length shall be determined according to factors such as the designed operation speed, curve radius and terrain conditions. If the designed operation speed is 350 km/h and the radius of curve is 12,000 m, the length of the transition curve with excellent comfort level (the comfort levels are classified into fair, good and excellent) shall be 370 m.

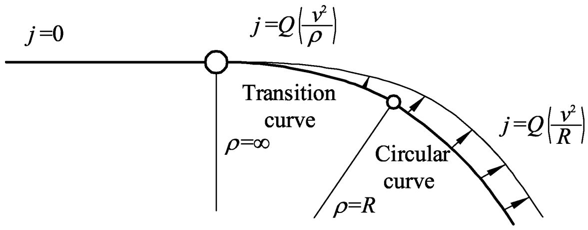

Figure 1.1 Schematic Diagram of the Transition Curve

4) Intermediate straight line

When a train is running on curves of same or opposite sense, the stress conditions will be extremely complicated. In addition to turning around the longitudinal axis of the line due to the super elevation of the outer rail, the train will also be influenced by the impact at the starting and ending points of the transition curve and the unbalanced centrifugal acceleration change. Therefore, a straight line section must be added between the curves of same or opposite sense, that is, intermediate straight line. The intermediate straight line shall be as long as possible, especially the intermediate straight line for curves of opposite sense shall be longer, which is beneficial to operation safety. This is because when a train passes through curves of opposite sense, the unit curve additional resistance will be greater than that of a train passing through a single curve, which will affect the stability and safety of the train in operation.

The minimum length of the intermediate straight line between adjacent curves is 0.5v (m) for HSRs in France, and the minimum length of the intermediate straight line for HSRs in Germany is calculated as 0.4v (m). The minimum intermediate straight line of the proposed HSRs in China will be determined according to the following formula:

Under normal conditions: $l_{min}=0.8v_{max}$

Under difficult conditions: $l_{min}=0.6v_{max}$

In which, v_{max} is the highest operation speed of the train.

5) Distance between centers of tracks

The distance between the centerlines of two adjacent tracks is referred to as the distance between centers of tracks. When two trains meet on a high-speed double-track railway, a huge crossing pressure wave will be generated, causing the train to shake laterally, which will directly affect the operation performance of the train. Therefore, appropriate distance between centers of tracks shall be selected according to the specific situation. Details about the sectional and in-station distance between centers of tracks for HSRs in China are listed in Table 1.4.

Table 1.4 Distance between Centers of Tracks for HSRs in China

S/N	Description		Minimum Distance Between Centers of Tracks/mm
1	Sectional double-track	v=160 km/h	4,200
		160 km/h<v≤200 km/h	4,400
		200 km/h<v≤250 km/h	4,600
		250 km/h<v≤300 km/h	4,800
		300 km/h<v≤350 km/h	5,000
2	The second track and the third track in three-track and four-track sections		5,300
3	Main tracks in station	v≤250 km/h	4,600
		250 km/h<v≤300 km/h	4,800
		300 km/h<v≤350 km/h	5,000
4	In-station main track and adjacent receiving-departure track		5,000
5	Receiving-departure track and adjacent receiving-departure track		5,000
6	Catch siding and other tracks		5,000

6) Ruling gradient

The ruling gradient has an impact on both operation and engineering. In terms of operation, if the gradient increases, the traction mass will be reduced and the train speed will be decreased; in terms of engineering, the ruling gradient can adapt to the terrain conditions and the track construction work amount can be reduced.

In addition to terrain conditions, the maximum gradient of HSR lines is also directly related to the traction power, tractive characteristics and braking performance of high-speed multiple unit trains. Since the high-speed train has a small mass and a large traction power, it can run at high speed on a line with a large gradient. For example, the maximum gradient of the Tokaido Shinkansen in Japan is 20‰, and the ruling gradient of the TGV southeast line in France is 35‰. In China, it is required that the maximum gradient should not be greater than 20‰ for main tracks in sections and not be greater than 30‰ under difficult conditions according to technical and economic comparison.

7) Radius of vertical curve

On the profile of a line, the curve connecting two adjacent grade sections with the point of gradient change as the intersection is called as the vertical curve. For main tracks of HSR lines, if the gradient difference between adjacent grade sections is greater than or equal to 1‰, vertical curve shall be set. Generally, the vertical curve will be circular curve, and its minimum length must not be less than 25 m.

In addition to ensuring that decoupling or derailment will not occur when the train passes through the point of gradient change, the effect of vertical centrifugal acceleration and centrifugal force generated on the vertical curve on passenger comfort shall also be considered when the radius of vertical curve is determined. The radius of vertical curve is related to the operation speed. The higher the operation speed is, the larger the radius of vertical curve shall be. Since the construction and maintenance work amount will be increased when the radius of vertical curve is increased to a certain degree, it is required in China that the radius of the vertical curve of HSRs shall not be greater than 30,000 m, and the minimum radius of the vertical curve shall be determined according to the designed operation speed of the section where the curve is located. For example, if the designed operation speed is 350 km/h, the minimum radius of vertical curve shall be 25,000 m.

2. Subgrade

The subgrade is an important part of the sub-rail foundation and is the key for ensuring high-speed, safe and comfortable operation of the train. The stability and firmness of the subgrade are directly related to the quality of the line and the normal operation and safety of the train. The subgrade structure shall have adequate strength, stability and durability.

The cross-section width of the subgrade shall be determined according to different conditions and requirements, taking into account the effects of factors such as the designed speed, track type, distance between centers of tracks, cable troughs, supporters of the overhead catenary system (OCS), and shoulder width. For the shoulder width of the ballasted track, the shoulder width of the sections with the designed speed of 200 km/h shall not be less than 1.0 m; the shoulder width of the sections with the designed speed of 250 km/h and higher shall not be less than 1.4 m for double-track sections and shall not be less than 1.5 m for single-track sections. The shoulder width of ballastless track shall be determined according to the type of ballastless track, cable troughs and foundation type of OCS to ensure good operating conditions and safe operation of high-speed trains.

3. Track Structure

The HSR track structures can be divided into two types: ballasted track and ballastless track, dominated by ballastless track.

1) Ballasted track

The overall structure of the track is ballasted track, but the track components have been improved and reinforced. Since the ballasted track has the advantages of simple structure, low engineering cost, fast laying speed, and easy repair of track deformation, it is also widely used for HSRs, such as HSRs in France and Germany.

2) Ballastless track

The ballastless track is a new type of sub-rail foundation developed on the basis of monolithic concrete bed. After being constructed, the track will be stable and smooth, requiring less maintenance work. However, the construction cost, the track rigidity, and the train vibration and noise generated will be high. The noise generated during train operation will be 3 to 8 dB higher than that of the ballasted track.

It is stipulated in the *Regulations on Railway Technical Management* for HSRs in China that ballastless tracks can be adopted for new railways with a designed speed of 300 km/h or above, as well as sections with tunnels or tunnel groups longer than 1 km. The main track rails shall be 60 kg/m rails with a fixed length of 100 m. The main track and the receiving-departure track shall be trans-section continuously welded rail tracks laid at one time. The insulated joints shall be glued insulated joints.

1.2 General Situation of HSR Development in Major Countries

At present, many countries in the world have built HSRs, and the HSRs in Japan, France and Germany have been operated for a long time.

1.2.1 HSRs in Japan

Japan is the first country in the world to build a practical high-speed railway. On October 1, 1964, Tokaido Shinkansen (Tokyo-Shin-Osaka High-speed Railway), the first railway built fully according to the technical conditions for high-speed train operation in the world, was officially put into commercial operation, which inaugurated a new era for not only the Japanese railway but also the world's railway.

The Tokyo-Shin-Osaka Shinkansen line is 515.4 km long in total. The 0-series high-speed multiple unit train was operated on the line, with a maximum operation speed of 210 km/h and a non-stop travel time of 3 hours which is 21% shorter than the travel time spent before the line was put into operation. The number of train pairs operated on this line per day increased from 30 pairs when the line was put into operation to 137.5 pairs in 1976, and the annual passenger transport capacity increased from 11 million person-time in 1964 to 85 million person-time in 1976. After the Tokaido Shinkansen was put into operation, it brought about good economic and social benefits. Since then, Japan has vigorously developed the Shinkansen and upgraded relevant technologies continuously. The operation speed of the Sanyo Shinkansen and Tokaido Shinkansen has been increased to the current 300 km/h and 270 km/h, respectively, and the operation speed of the Tohoku Shinkansen has been increased to 320 km/h. Nowadays, the main and branch lines of the Shinkansen have covered the mainland of Japan, with a total mileage of about 2,452 km. The Shinkansen is known as "the backbone for the economic take-off of Japan".

1.2.2 HSRs in France

France is also a country engaged early in the research on increasing train speed in the world. In 1955, a world record of 331 km/h train speed was set in France through electric locomotive traction. In 1971, the French Government approved the construction of the southeast line of TGV (short for "train à grande vitesse", which means high-speed train) from Paris to Lyon, with a total length of 417 km. The construction was officially started in October 1976 and the whole line was completed and put into operation in September 1981. After the line was put into operation, the travel time from Paris to Lyon was shortened from about 4 hours to 2 hours; the maximum running speed of the train on the line was 270 km/h (currently 300 km/h after reconstruction); the passenger transport capacity increased rapidly, and good economic benefits were brought about. The successful operation of the southeast line of TGV proves that HSR is a competitive modern transportation means. In 1989 and 1990, France built the TGV-Atlantique from Paris to Le Mans and Tours, with the maximum running speed of the train up to 300 km/h. In 1993, France's third high-speed railway, the northern line of TGV, was put into operation. The northern line of TGV, also known as the Nordic Line, runs from Paris to London (via Lille) through the Channel Tunnel, and is connected to Brussels in Belgium, Cologne in Germany, and Amsterdam in the Netherlands. It is an important international channel. At present, HSRs in France have formed a network of TGV high-speed railway trunk lines that centers on Paris and radiates through the whole country, and is also connected to neighboring countries. The mileage of the new HSR lines in France is about 2,000 km, while the network coverage in which the high-speed train TGV can provide services reaches more than 6,000 km; the maximum running speed of the train can reach 320 km/h.

The target speed has always been the ultimate pursuit in the development of HSRs in France. In 1981, the operation speed recorded in the test of the first-generation high-speed multiple unit trains in France, the high-speed multiple unit trains of the southeast line ("TGV-PSE" for short) reached 380 km/h, and the commercial operation speed of the multiple unit trains reached 270 km/h, transcending the concept of traditional railway operation speed. In May 1990, the world record of 515.3 km/h was set by the second-generation high-speed multiple unit trains, the multiple unit trains of TGV-Atlantique ("TGV-A" for short), which attracted more attention worldwide. On April 3, 2007, the V150 high-speed multiple unit train set the highest test record of wheel-rail train operation speed of 574.8 km/h. The V150 test train is shown in Figure 1.2.

Figure 1.2 V150 Test Train in France

1.2.3 HSRs in Germany

Germany has a solid technical foundation for developing HSRs. In 1988, the test speed of its electric traction train hit the 400 km/h mark and reached 406.9 km/h. However, due to various reasons, HSRs in Germany were not put into operation until the 1990s. At present, Inter City Express (ICE) high-speed trains can reach most major cities in Germany, including Hamburg, Munich, Berlin, Frankfurt, Stuttgart, Cologne, and Dusseldorf, with a total mileage of about 1,000 km. The range in which ICE trains can provide service reaches more than 6,300 km, and the maximum running speed of the train reaches 300 km/h.

1.2.4 HSRs in China

Although the development of HSRs in China was 20 to 30 years later than that in developed countries, HSRs have been developed rapidly since the beginning of the 21st century, with large construction scale and high transport capacity which are remarkable in the whole world. The HSR technology developed by China Railway on the basis of six major speed-ups on existing lines and the construction of passenger dedicated lines has been among the highest in the world.

1. Six Major Speed-ups on Railways in China

In the mid-1990s, the railways in China faced a situation of slow speed and severely insufficient transport capacity. By the end of 1996, the operation speed of passenger trains in China was only 110 km/h and the traveling speed was only 49.5 km/h, which could not meet the needs of the majority of passengers.

In the 10 years from April 1, 1997 to April 18, 2007, six major speed-ups had been implemented for railways in China and tremendous achievements had been made. The scope of the sixth major speed-up includes Beijing-Harbin Railway, Beijing-Guangzhou Railway, Zhejiang-Jiangxi Railway, Shanghai-Hangzhou Railway, Beijing-Shanghai Railway, Lanzhou-Lianyungang Railway, Qingdao-Jinan Railway, and other main lines, covering 17 provinces, municipalities and autonomous regions across the country. The maximum running speed of the passenger trains could be higher than 200 km/h after the speed-up. The operation speed in some sections of the Beijing-Harbin Railway, Beijing-Shanghai Railway, Beijing-Guangzhou Railway, and Qingdao-Jinan Railway could even be higher than 250 km/h, which marks that the speed-up on existing railways in China has reached the world's advanced level. This speed-up is characterized by putting the home-made EMUs with speeds of 200 km/h and higher into operation. After this speed-up, the length of lines with the operation speed of 200 km/h and higher reached 6,003 km, and the passenger transport capacity was increased by more than 18%.

Through the six major speed-ups of existing railway lines, a complete technical theory system for speeding up existing railway lines to the operation speed of 200 km/h and higher has been established and a complete set of technical measures has been proposed, which can provide strong technical support for the construction and operation management of HSRs in China.

2. Development of HSRs in China

With the continuous improvement of the operation speed of railways, the idea of great-leap-forward development was put forward for railways. At the beginning of 2004, the MID-TO-LONG TERM RAILWAY DEVELOPMENT PLAN (hereinafter referred to as the “*Plan*”) which determined the blueprint for railway development in China was approved by the State Council. In order to implement the *Plan*, according to the spirit of the *Meeting Minutes*, the former Ministry of Railways organized the introduction of advanced technologies for multiple unit trains with the operation speed of 200 km/h and higher through two purchases in 2004 and 2005, following the principle of “advancement, maturity, economic efficiency, applicability, and reliability”; carried out comprehensively the work such as the digestion and absorption of advanced technologies and the enhancing of independent innovation, to improve the level of rolling stock equipment manufacturing industry in China, meet the needs of railway passenger transport development and transport capacity expansion, and alleviate the “bottleneck constraint” imposed by railway transportation on the national economy.

In October 2004, the former Ministry of Railways organized and completed the signing of the contracts for procurement of 140 multiple unit trains with the operation speed of 200 km/h and successfully introduced advanced technologies of Kawasaki

Heavy Industries, Bombardier and Alstom for multiple unit trains.

In November 2005, the former Ministry of Railways organized and completed the signing of the contract for procurement of 60 multiple unit trains with the operation speed of 300 km/h and successfully introduced advanced technologies of Siemens for multiple unit trains. At the same time, based on the technologies introduced in 2004, CRRC Qingdao Sifang Co., Ltd. has also speeded up its multiple unit trains to 300 km/h.

In 2007, the domestically produced “Harmony” series EMUs with a speed of 250 km/h were off-line and put into use in batches, marking the era of high-speed railways in China.

On August 1, 2008, the Beijing-Tianjin Intercity Railway was put into operation, with a maximum operation speed of 350 km/h, setting the record of the world's highest commercial operation speed. This marks that China has mastered the core technology for high-speed trains at the speed level of 350 km/h.

On December 26, 2009, the Wuhan-Guangzhou High-Speed Railway was put into operation. It was the railway with the longest one-time completed mileage and the most complicated engineering type in the world, setting a series of new world records, such as train meeting inside tunnels at the speed of 350 km/h and double-pantograph current collection of two coupled trains. This indicates that China can build world-class HSRs with complicated engineering types, large construction scales and long distances.

On September 28, 2010, in the operation test of Shanghai-Hangzhou High-speed Railway, the maximum test speed of the Harmony CRH380A high-speed train with independent intellectual property rights reached 416.6 km/h, setting the record of the highest speed of railways in operation in the world.

On December 3, 2010, in the Xuzhou-Bengbu section of the Beijing-Shanghai High-speed Railway, the maximum operation test speed of the CRH380A high-speed train reached 486.1 km/h, which once again refreshed the record of the operation test speed of railways in the world.

At the end of August 2011, the Beijing-Shanghai High-speed Railway was officially put into operation, with a maximum operating speed of 300 km/h.

On September 21, 2017, China's self-developed standard EMU “Fuxing” was the first to achieve the operation speed of 350 km/h on the Beijing-Shanghai High-speed Railway, making China became the country with the highest commercial operation speed of HSRs once again in the world.

On June 7, 2018, China Railway Corporation launched the field test of the automatic train operation system (CTCS3+ATO train control system) for high-speed EMUs on the Beijing-Shenyang High-speed Railway, which indicates that an important phased achievement was made in the independent innovation of key core technologies for smart HSRs in China and the overall technical level of Chinese HSRs was still among the highest in the world.

According to the requirements of the *Mid-to-Long Term Railway Development Plan*, China has built a number of HSRs with a design speed of 350 km/h and the world's advanced technological level, including Beijing-Tianjin Intercity Railway, Shanghai-Nanjing Intercity Railway, Beijing-Shanghai High-speed Railway, Beijing-Guangzhou High-Speed Railway, and Harbin-Dalian High-speed Railway. By the end of 2012, the operating mileage of HSRs in China had reached 9,356 km, ranking the first in the world. By the end of 2017, the operating mileage of HSRs in China had reached 25,000 km, accounting for 66.3% of the world's total mileage of HSRs, ranking still the first in the world.

Through independent innovation, China has carried out survey, design and engineering construction of HSRs relying on its own power, systematically mastered technologies for the construction, operation management and maintenance of HSRs, such as complex subgrade treatment, long bridge construction works, large-section tunnel construction works, track construction works, traction power supply, communication signals, and passenger terminals, established complete technological platform for high-speed train design, manufacturing, testing, and evaluation, mastered a series of key and core technologies for high-speed trains, and formed a technical system and standard system with independent intellectual property rights, which has promoted the rapid development of social economy in China.

By 2020, the total mileage of HSRs in China will reach 30,000 km, covering more than 80% of large cities; by 2025, the total mileage of HSRs will reach more than 38,000 km. At that time, the travel time from Beijing to all major provincial capital cities in China will be within 8 hours.

1.3 Technical Characteristics and Composition of Multiple Unit Trains

1.3.1 Definition and Classification of Multiple Unit Trains

1. Definition of Multiple Unit Trains

The multiple unit train is a trainset composed of several motor cars and trailer cars or only motor cars fixedly coupled together for a long time. The powered cars in multiple unit train are called motor cars (“M”), while the unpowered cars in multiple unit train are called trailer cars (“T”). Since both ends of a multiple unit train are equipped with a driver's cab, the multiple unit train can run back and forth on a railway line. In addition to the multiple unit trains for high-speed railways, intercity passenger transport and suburban passenger transport, metro trains and light-rail trains in cities also belong to the category of multiple unit trains.

2. Classification of Multiple Unit Trains

Multiple unit trains can be classified according to different standards and methods, which can be summarized mainly as follows:

1) Classification based on the speed level

(1) Quasi-high-speed multiple unit trains: Multiple unit trains with a running speed of 160-200 km/h;

(2) High-speed multiple unit trains: Multiple unit trains with a running speed of 200-400 km/h;

(3) Super-fast multiple unit trains: Multiple unit trains with a running speed higher than 400 km/h.

2) Classification based on the traction power

(1) Electric Multiple Unit (EMU)

Electric traction has the characteristics of large traction power, small axle load, good economic efficiency, and being environmentally friendly. At present, electric traction is adopted for more than 80% of high-speed multiple unit trains.

(2) Diesel Multiple Unit (DMU)

Diesel traction has the characteristics of low investment, quick effect, and good flexibility. It is often adopted in high-speed railway sections which have not been electrified, or as a transition form of traction in the development of HSR construction.

(3) Magnetically Levitated (Maglev) Multiple Unit

The maglev train is very different from traditional trains. The attractive force (or repulsive force) generated by the electromagnetic system is made use of to hold up (or lift) the train and suspend it on the guide rail; the electromagnetic force is used to guide the train, and the linear motor is used to convert the electric energy into propulsive force which can drive the train to run forward at high speed. Since the wheel and rail are not in contact and there is no frictional resistance between the wheel and rail, maglev trains are suitable for super-fast operation and the speed can reach more than 500 km/h. A maglev train is shown in Figure 1.3.

3) Classification based on power configuration modes

(1) Power-concentrated multiple unit trains

Power-concentrated multiple unit trains refer to the multiple unit trains formed by motor cars on both ends and trailer cars in the middle, such as ICE-1 and ICE-2 in Germany.

Figure 1.3 Maglev Train

(2) Power-distributed multiple unit trains

Power-distributed multiple unit trains refer to the multiple unit trains formed by multiple units which consist of a certain number of motor cars and trailer cars.

4) Classification based on bogie connection modes

(1) Independent multiple unit trains

Independent multiple unit trains adopt traditional connection between the car body and the bogie: each car body is placed on two bogies and the cars are coupled with tight-lock couplers; the cars can travel independently after being decoupled.

(2) Articulated multiple unit trains

The car bodies of articulated multiple unit trains are articulated with elastic hinges. The hinge joints are placed on a common bogie and the car could not be decoupled for independent traveling.

By combining the classification based on power configuration modes and the classification based on bogie connection modes, the multiple unit trains can be classified into the 4 types shown in Figure 1.4.

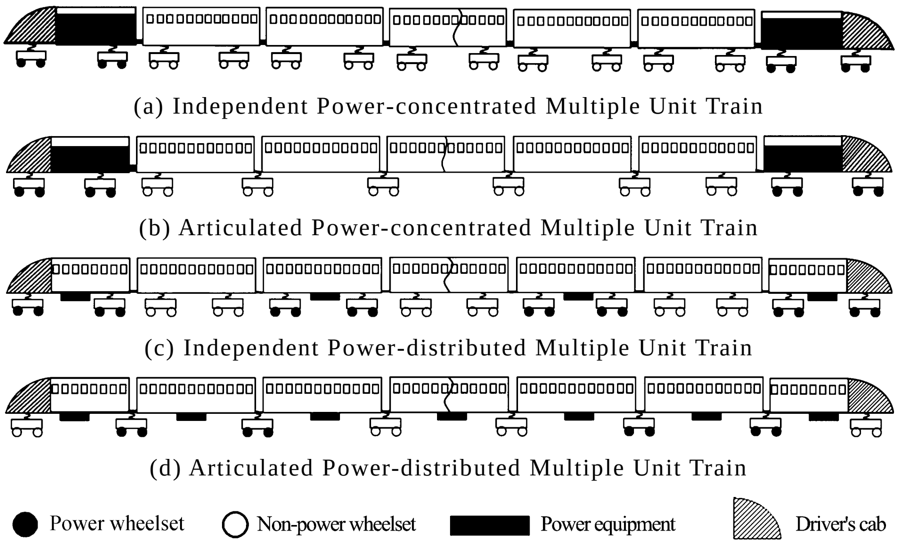

Figure 1.4 Schematic Diagram of the Classification of Multiple Unit Trains Based on both the Power Configuration Modes and the Bogie Connection Modes

1.3.2 Requirements of Multiple Unit Trains for Traction Power

The requirement of a multiple unit train for traction power is determined according to the total mass of the multiple unit train, the maximum operating speed and the specific train resistance at this speed. The traction power N required by a multiple unit train is calculated as follows:

$$N = \frac{Q \cdot \omega \cdot v_{\max} \cdot k}{3,600} \text{ (kW)} \tag{1.1}$$

Where, Q —Total mass of the multiple unit train, t;

ω—Specific train resistance, N/t;

$v_{\max}$ —Maximum operating speed of the train, km/h;

k —Margin coefficient

The resistance during train operation includes the basic resistance of train operation and various additional resistances.

The basic resistance of train operation is composed of the air resistance and mechanical resistance of the train. The mechanical resistance is caused by bearing friction, wheel-rail rolling friction, sliding friction, vibration, and shock.

The additional resistances include gradient resistance, curve resistance, tunnel air additional resistance, and starting resistance.

The basic resistance of a train varies with the running speed. When the train is running at low speed, the mechanical friction resistance will be the main component of the basic resistance; when the running speed reaches 200 km/h, the air resistance will account for 70% of the basic running resistance; if the running speed is further increased, the proportion of air resistance will continue to increase. The air resistance is in direct proportion to the square of the train's running speed. The reason why the train needs high traction power is that the higher the train's running speed is, the greater the air resistance will be, and this rapidly increasing air resistance will become the main resistance when the train is running. In order to overcome the running resistance of the train, high traction power is required, and the power and the maximum speed of the train have a cubic function relationship.

1.3.3 Characteristics of the Power Configuration of Multiple Unit Trains

As previously mentioned, there are two power configuration modes of multiple unit trains, namely the power-concentrated configuration and the power-distributed configuration.

A motor car in a power-concentrated multiple unit train is a complete power unit, which is similar to a traditional locomotive; the electrical equipment and power devices are installed on the motor car in a centralized manner, and only the wheelsets of the motor car are driven by the motor, as shown in Figure 1.5. The motor car is used for train towing only and will not carry passengers, while the trailer car only carries passengers but will not tow the train.

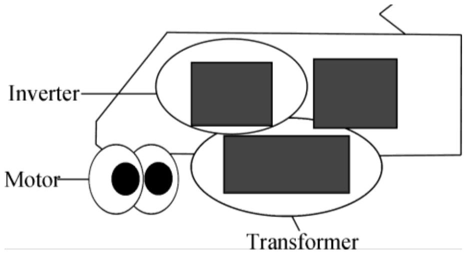

Figure 1.5 Power-Concentrated Configuration

The French TGV-Atlantique (TGV-A) adopts the power-concentrated configuration mode. In the 12-car formation, the motor cars are arranged at both ends, and the trailer cars are arranged in the middle, that is, 2 motor cars + 10 trailer cars (referred to as 2M + 10T).

In power-distributed multiple unit trains, usually 2 or more cars will form a power unit, and all or multiple wheelsets are of motor-driven type; the main electrical equipment will be suspended under the car to achieve relatively balanced train axle load; all cars can carry passengers, as shown in Figure 1.6. All Harmony EMUs in China adopt the power-distributed configuration mode.

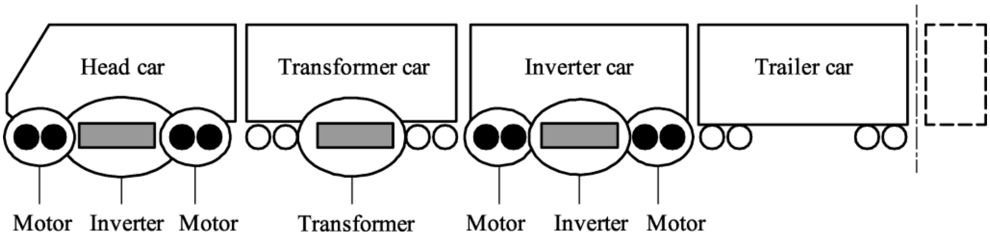

Figure 1.6 Power-Distributed Configuration

The above two types of multiple unit trains have their own characteristics and development process. From the perspective of their production and development process, what type of multiple unit trains are used in a country or for a high-speed railway may be related to the operating conditions, operating experience and traditional technologies. Therefore, it is impossible to generalize their advantages and disadvantages. Only by analyzing their technical characteristics in detail, combined with specific operation requirements and service conditions, can we draw clear conclusions and develop reasonable type selection schemes.

1. Characteristics of Power-Concentrated Multiple Unit Trains

1) Advantages of power-concentrated multiple unit trains

(1) Power-concentrated multiple unit trains are similar to traditional trains, which is convenient for operation management and maintenance management as customary.

(2) The monitoring and technical maintenance are convenient in the operation of mechanical and electrical equipment.

(3) The passenger coaches have low noise and vibration, with higher comfort level.

(4) The head car for traction can be detached or attached, which is convenient for the train to enter the existing line. Or even the replacement with diesel locomotive can be achieved, so that the train can be operated on a non-electrified railway.

2) Disadvantages of power-concentrated multiple unit trains

(1) Since the motor car could not carry passengers, the passenger capacity is reduced.

(2) It is difficult to reduce the axle load of the motor car.

(3) An insurmountable contradiction exists between the large adhesive traction force of the motor car and the requirements for small axle load of the wheels.

(4) The braking capacity of the motor car is limited by adhesion, and the braking performance of the train is not good.

2. Characteristics of Power-Distributed Multiple Unit Trains

1) Advantages of power-distributed multiple unit trains

(1) The motor car can also carry passengers, which increases the passenger capacity of the multiple unit train.

(2) The power and mass of traction power equipment and traction motor are distributed to each car, which makes it easier to meet the requirement of reducing the axle load of high-speed trains.

(3) The traction force is distributed on each motor car wheel, which can solve the contradiction between the large traction force and the axle load limitation of the high-speed train.

(4) The dynamic braking power can be fully utilized to ensure good braking performance of the train.

2) Disadvantages of power-distributed multiple unit trains

(1) Since the power equipment is suspended under the vehicle, the vibration and noise generated by the equipment will affect the comfort in the coaches.

(2) The failure rate of distributed power equipment will be relatively high.

(3) The train can only be formed by units and could not run on non-electrified railways.

(4) Since the operation and maintenance management systems and practices of power-distributed multiple unit trains are different from those of traditional trains, a new maintenance system must be established for them.

1.3.4 Composition of Multiple Unit Trains

A multiple unit train generally consists of the following 7 parts.

1. Car Body

A multiple unit train car body may have driver's cab or have no driver's cab. It is a place for accommodating passengers and the driver, and also the foundation for the installation and connection of other equipment and components.

2. Bogie

The bogies of multiple unit trains can be divided into power bogies and non-power bogies. All or partial axles of the power bogie can be driving axles. The bogie is placed between the car body and the track and used for towing and guiding the train to travel along the track; it will bear and transmit various loads from the car body and the track, and mitigate shock and vibration. It is a critical component for ensuring the quality and safety of train operation. Generally, the bogie is composed of wheelset axle box device, frame, spring suspension device, car body support device, and brake device. A power bogie may also have traction motor and transmission device.

3. Connection Buffer Device

Connection buffer devices must be used when a multiple unit train is formed by cars. The mechanical connection requires mainly the coupler and draft gear and the vestibule diaphragm. There will also be electrical and air hose connections between cars, connections of high-voltage electrical apparatus, auxiliary system and train power supply connections, and control system connections.

4. Brake Device

The brake device is necessary for ensuring train deceleration, accurate train stopping and safe train operation. The compound (dynamic-air) braking mode is often adopted for multiple unit trains. The multiple unit train braking system includes the dynamic braking system (such as regenerative brake), air braking system (including air source), electronic anti-skid device, and basic braking device.

5. Interior Equipment

The interior equipment refers to fixed accessories inside the vehicle that serve passengers, such as interior electrical appliances, water supply, ventilation, heating device, air conditioners, seats, windows, doors, luggage racks, and passenger information service system.

The passenger information service system includes the following 3 subsystems:

1) Public address system

The public address system works as a separate subsystem, and if necessary, the public address can be controlled through the entertainment system.

2) Display system

The display system obtains information from the train computer as a separate subsystem.

3) Entertainment system

The entertainment system consists of separate transmitting system and receiving system. The transmitting system controls the information system of the train, and the receiving system controls the receiver control panel and the video monitoring network.

6. Traction Drive System

The traction drive system provides traction power for the multiple unit train. It consists of mainly the main circuit, high-voltage equipment, pantograph, main circuit breaker, other high-voltage equipment, main transformer, traction converter, traction motor, and electric drive system protection.

7. Auxiliary Power Supply System

The auxiliary power supply system refers to a system that provides electric energy for all loading equipment that requires electricity except the traction power system. The auxiliary power supply system is mainly composed of auxiliary converter, battery, and charger.

The system provides power supply for mainly the following equipment: air compressors, cooling ventilators, oil pump/water pump motors, air conditioning systems, heating equipment, lighting equipment, passenger service equipment, emergency ventilation devices, and maintenance equipment. In addition, the auxiliary power supply system also has an emergency power supply function. The emergency power supply includes power supply for emergency ventilation in the passenger coaches, emergency lighting, emergency display, maintenance, and communication and its control.

1.3.5 Main Technical Characteristics of Multiple Unit Trains

1. Excellent Aerodynamic Profile

As the running speed of a train increases, on the one hand, the dynamic effect of the air will exert an influence on the train and train performance; on the other hand, the aerodynamic phenomena caused by high-speed train operation will also exert an influence on the surrounding environment. As shown in Figure 1.7, for high-speed multiple unit trains, the streamlined design of the car body and head shape is very important. Such streamlined design has the following advantages:

(1) Reducing effectively the surface pressure and air resistance of the train;

(2) Reducing effectively the crossing pressure wave and the train surface pressure and train induced wind in tunnels;

(3) Ensuring stable train operation

Figure 1.7 Streamlined Design of the Head Shape for CRH380A EMU

2. Lightweight Design of Car Body Structure

The lightweight design of car body structure has the following advantages:

(1) Saving traction power;

(2) Minimizing axle load of high-speed multiple unit trains;

(3) Reducing the damage to the track structure and rolling stock structure caused by the dynamic effect due to high speed;

(4) Improving the riding comfort of passengers.

At present, aluminum alloy and stainless steel are used as the main materials of high-speed train bodies in various countries in the world. From the perspective of the development trend, aluminum alloy will become the dominant material for car bodies of multiple unit trains.

3. High Performance Bogie

The bogie is a key component of the multiple unit train. It can be said that the process of increasing the train running speed is also the process of the development of high-speed bogies. To improve the running speed of trains, high-performance bogies must be designed and manufactured to ensure the stability, smoothness and good curve passing performance during high-speed operation, so as to ensure the safe operation of high-speed trains, the riding comfort, and the reduced maintenance workload. Stability is also called as safety performance, which refers to the basic performance of ensuring that the train will not derail, overturn or cause damage to the track when running within the specified maximum speed range and under the specified track conditions. Smoothness is the basic performance that the equipment can be operated stably and the passengers can feel comfortable when the train runs within the designed maximum speed range and under the specified track conditions. When the train passes through a curve section, excessive lateral pressure will be generated, resulting in violent wear of the wheel and rail. Therefore, good curve passing performance is also the basic performance for ensuring the safety of the train.

4. Compound Braking Technology

High-speed trains pose severe challenges to braking technology. Since the braking energy of a train is in direct proportion to the square of the speed, the braking energy of high-speed trains at the speed of 200-300 km/h is 4-9 times that of normal-speed trains. The capability of traditional air braking is far from meeting the needs of high-speed trains. Therefore, a compound braking system that can provide strong braking force and make better use of adhesion must be designed for high-speed trains.

The compound braking system is mainly composed of the brake control system, electrical dynamic braking system, air braking system, computer-controlled anti-skid device, and non-adhesive brake device. The air brake refers to the tread brake and disc brake commonly used on trains. The electrical dynamic brake includes regenerative brake, rheostatic brake, eddy current brake, and electromagnetic rail brake. For braking of high-speed multiple unit trains, the electrical dynamic braking will be dominated, supplemented by air braking in the case of insufficient braking capacity.

The braking system of high-speed multiple unit trains shall meet the following performance requirements:

(1) The requirements for the braking capacity shall be met. The braking of high-speed trains includes speed regulating braking and stopping braking, which requires strong braking capacity and fast response.

(2) The requirements for riding comfort shall be met. Computer control shall be adopted to reduce the rate of speed change at the same time of increasing the average speed. The impact force of braking shall be small, which will improve the riding comfort of passengers.

(3) The requirements for safety performance and reliability shall be met. The design of the braking mode shall be optimized to realize multi-stage braking control and

ensure that various braking modes of the compound system can share the braking energy properly and hierarchically under normal conditions.

(4) The redundancy of braking capacity shall be designed. It shall be ensured that once one of the braking modes fails, other braking modes shall be able to make supplements.

In order to meet the above performance requirements, a series of new technologies needs to be used for high-speed multiple unit trains, including: high-power disc brake; compound braking mode, that is, air disc brake + electrical dynamic brake (regenerative brake) + non-adhesive brake (eddy current brake and magnetic rail brake); braking force control according to the speed to make full use of the adhesive force; high-performance anti-skid device and computer control. Therefore, electrical dynamic braking technology and brake control technology will become the key to the compound braking technology.

5. Tight-lock Coupler and Draft Gear

The coupler and draft gear play the role of transmitting longitudinal force in the train, which directly affects the magnitude of the longitudinal impact of the train, the riding comfort of passengers and the safety performance of the train. The requirements for the safety performance and reliability of the coupler and draft gear are much higher for high-speed trains.

At present, tight-lock coupler and draft gear are widely used for high-speed trains around the world. The longitudinal gap between the two coupler connection surfaces is generally less than 2 mm, and the vertical and horizontal displacement is also very small, which improves the smooth operation of the train and ensures the automatic connection of electrical circuits and air hoses.

6. AC Drive Technology

The converter device of the AC drive system converts single-phase AC power into three-phase AC power with frequency and voltage regulation. The AC drive technology of high-speed trains has gone through the development process from DC drive to AC drive. For high-speed trains that require high power, low axle load, good adhesion utilization, and high vehicle utilization rate, AC drive technology has significant advantages.

AC-DC drive technology is adopted for all early electric traction drive systems, and DC motor is used for driving. Due to the large mass of the DC motor required for unit power, an insurmountable contradiction exists between the high-power driving and the axle load reducing (especially the unsprung weight reducing) required by high-speed trains. Therefore, the power of the DC traction motor generally does not exceed 500 kW.

In the AC drive system, two different traction motors are often used, namely AC synchronous motor and AC asynchronous motor. For example, self-commutated three-phase synchronous traction motor is used for high-speed trains in France, and the power of a single motor is increased to 1,100 kW. Compared with traditional DC traction motors, AC traction motors have the following advantages:

(1) Simple structure and reliable operation;

(2) Small size and light weight;

(3) High rated output power;

(4) Low cost, easy maintenance, high efficiency, etc.

The advancement of inverter technology and AC motor control technology provides conditions for the use of asynchronous traction motor for driving. Therefore, AC-DC-AC drive system and the use of asynchronous motor for driving will be the main development trend of the high-speed train traction drive system.

7. Automatic Train Control (ATC) System and Fault Diagnosis Technology

The ATC system plays an important role in ensuring the safe operation of high-speed trains. All countries in the world have attached great importance to the research and development of the ATC system during the development of HSRs, and developed a variety of basic technical equipment, such as the automatic train protection (ATP) system, global positioning system (GPS), on-board intelligent control system, and on-board computer automatic monitoring and diagnostic system. At present, the automatic control methods of HSRs can be divided into two main categories: one is the control method dominated by equipment control and supplemented by human control, represented by the ATC method adopted by the Shinkansen in Japan; the other is the human-machine combined control method dominated by human control, mainly represented by the TVM300 safeguard system and the improved TVM430 safeguard system adopted by the high-speed trains (TGV) in France, and the FRS speed locomotive signaling and the LZB double-track cross-cable transmission train control equipment adopted by the ICE high-speed trains in Germany.

8. Car Sealing, Sound Insulation and Feces Collection and Treatment Technology

Good sealing of the car body is also a key technology for high-speed trains. When multiple unit trains are running at high speed, especially when two multiple unit trains meet in the tunnel, the air pressure outside the head and tail cars changes greatly, and the fluctuation of the pressure outside the cars will be transmitted into the coaches, making passengers feel uncomfortable. The eardrum will be oppressed in less severe cases; dizziness and nausea, or even eardrum rupture will be caused in severe cases. Many countries have conducted studies on the impact of pressure waves on the riding comfort of passengers.

As the running speed of the multiple unit train increases, the noise generated will also increase. The noise transmitted into the coaches will affect the riding comfort of passengers and cause noise pollution along the railway line. Therefore, weakening the noise source and improving the sound insulation performance of the car body are also key technologies for the development of high-speed multiple unit trains.

As the running speed of the multiple unit train increases, it is imperative to use closed feces collection devices and dispose of sewage in a centralized manner. In addition, the problem of gas tightness of the coaches is also very prominent. Therefore, water supply and drainage system and feces collection and treatment system with good sealing performance must be used for high-speed multiple unit trains.

Fully enclosed toilets have been used for a long time on high-speed trains in Europe, the United States and Japan,with many different types. There are 4 main types of fully enclosed toilets: circulating toilets, vacuum toilets, jet toilets, and clean water flush toilet (semi-open) system with biological action treatment tanks.

9. High Performance Pantograph

The current collection process of the OCS-pantograph current collection system is a dynamic process where the pantograph slides between the catenaries under the OCS at the train running speed. This dynamic process includes the electrical status changes of various mechanical movements. The OCS-pantograph current collection in high-speed railway operation has some new characteristics, and the current capacity, applicable speed and safety performance of the current collection system have changed considerably. Therefore, high-performance pantograph shall be used for high-speed multiple unit trains to meet the requirements of high-speed current collection.

The pantograph of the high-speed multiple unit train must meet the following basic requirements:

(1) Constant contact pressure shall be maintained between the pantograph pan and the contact wire.

(2) The mass of the current collection and movement part shall be minimized as much as possible to ensure reliable electrical contact with the OCS.

(3) The air resistance shall be fully considered in the structural design, to reduce or even eliminate the impact of the air braking force on the contact pressure between the pantograph pan and the contact wire.

(4) The pantograph pan shall be adaptable to the contact state at high speed in terms of the material, shape and size, and shall have sufficient wear resistance.

(5) When the pantograph is raised or lowered, the initial action shall be rapid while the final action shall be relatively slow, so as to ensure rapid current interruption when the pantograph is lowered, and to prevent the pantograph from applying excessive impact load on the OCS and underframe when the pantograph is raised or lowered.

10. Pendulum Type Car Body Technology

When the train passes through a curve section, unbalanced centrifugal acceleration exceeding the allowable limit will make passengers feel uncomfortable. This unbalanced centrifugal acceleration is in direct proportion to the square of the train running speed, thus limiting the speed of the train as it passes through the curve.

In order to increase the speed of the train on the curve section, various types of pendulum trains have been developed abroad, that is, to make the train body tilt to the inside of the curve when the train passes through the curve through various measures. In this case, the train body will rotate by an angle against the rail surface and the rotating directions of the angle of the car body and the track superelevation angle will be consistent. The superelevation angle felt by passengers in coaches will be the sum of the actual superelevation angle of the track and the car body tilting angle, as shown in Figure 1.8. Therefore, the lateral component of the gravitational acceleration experienced by passengers will increase significantly, which can largely offset the centrifugal acceleration of the train and keep the unbalanced centrifugal acceleration felt by passengers within the allowable range. If the pendulum car body is adopted, the speed limit for running on the curve section can be increased by 30% to 40% and the travel speed can be increased by 15% to 20%. Figure 1.9 shows the pendulum train in Sweden.

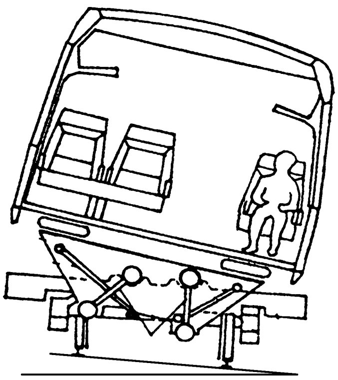

Figure 1.8 Schematic Diagram of the Pendulum Car Body

Figure 1.9 Pendulum Train in Sweden

Questions for Review

1. Please describe briefly the definition of HSR.

2. What are the characteristics of HSR passenger transport?

3. Please describe briefly the standards for HSR lines.

4. What are the advantages and disadvantages of the ballasted track and the ballastless track? Which type of track structure is adopted mainly for HSRs?

5. Please describe briefly the development of railways in China.

6. What are multiple unit trains? How can multiple unit trains be classified?

7. What are the two power configuration modes of multiple unit trains? Please describe briefly the advantages and disadvantages of these two modes.

8. What are the components of a multiple unit train?

9. What are the main technical characteristics of multiple unit trains?