



DESIGN OF HIGH-SPEED RAILWAY TURNOUTS

THEORY AND APPLICATIONS

Ping Wang



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Ping Wang

王平 著

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Preface

Since the publication of the first edition of *High-Speed Railway Turnouts: Design Theories and Application* in 2011, the book has been highly received by engineers in turnout design, manufacturing, and maintenance fields. The first edition was selected into “Three Hundred” Project of Originality Book Publication (held biennially, in which 100 outstanding books of originality will be selected respectively for the categories of humanities and social sciences, science and technology and literature, and children’s books) by SAPPRFT of the P.R.C. in 2013. The first edition summarized the design theories for high-speed turnouts developed by China.

By the end of 2014, Chinese high-speed railways have covered an operating kilometrage of up to 16,000 km, with more than 5000 sets of high-speed turnouts for 250 km/h and above and the longest service time of 6 years. Chinese high-speed railway turnouts have suffered many difficulties in the past. Specifically, the turnouts were exposed to degraded manufacturing and laying quality due to short construction period. In face of this problem, relevant administration had taken corresponding measures to assure the quality, such as resident supervision system, field laying, and acceptance and accurate adjustment based on CPIII. Previously, degraded riding quality and safety also occurred when high-speed train traveled in certain turnout, so this problem had been temporarily controlled by speed restriction for a period as the maintainers failed to find out the causes in due time. The problem was finally settled through the demonstration and analysis of relevant experts. Rail cracks had been a concern in certain turnouts, which had been settled by improving the reliability and safety of the turnouts by enhancing rail detection, developing turnout monitoring system and introducing RAMS management. This new edition is produced based on above practices, so as to supplement the theories and technologies in the field of manufacturing, laying, maintenance, and management of high-speed turnouts, and elaborate the measures for maintaining high smoothness in the life cycle of high-speed turnouts. This edition aims at introducing the technical performance of high-speed turnouts in depth, analyzing relevant causes of defects and damages accurately, providing reasonable solutions to any technical problems, and contributing to the scientific management of high-speed turnouts. In addition, it hopes to provide theoretical and technical support for the safe operation of Chinese high-speed railways, and benefit the rest of the world anyhow.

High smoothness is the key and core technology to ensure the riding safety, quality, and comfort of high-speed train in high-speed turnouts. This feature shall be controlled in all sectors from design to manufacturing, laying, and maintenance. The smoothness of a turnout is mainly reflected by the low dynamic force, strong constraint, and high reliability while withstanding train load, transmitting temperature load, and during the conversion in the main/diverging line. There are mainly four types of irregularity: structural irregularity induced by complicated wheel–rail relation, geometry irregularity caused by poor status of rail, fastening, and bed, status irregularity caused by manufacturing and assembly error of parts and conversion failure, and dynamic irregularity caused by uneven track bearing stiffness. These irregularities will cooperate with train systems and impact the dynamic response and dynamic characteristics of turnout structure during the passage of trains in the turnout, thus affecting the riding safety, quality and comfort in the turnout, as well as influencing the stability, durability, and service life of the turnout. This book will introduce the theories, structural design, manufacturing and laying technologies, and maintenance policies centering around high

smoothness of the turnout. In addition to the contents in the first edition, the design theories of CWR turnouts, design methods for CWR turnouts on bridge, manufacturing and laying technologies for high-speed turnouts, typical cases of irregularity control for high-speed turnout in use, and the maintenance and management technologies for high-speed turnouts will be elaborated in this edition.

The book includes 14 chapters:

Chapter 1 introduces the structural type, main technological requirements, and structural characteristics of high-speed turnouts, and compares the technical characteristics of high-speed turnouts in China, Germany, French, etc.

Chapter 2 mainly describes the design and application conditions, plane line types, traditional fundamental parameter method for plane line type design and that based on particle motion, and introduces the turnout plane line type design methods and design software developed based on rigid body motion and wheel–rail vibration during the development process of Chinese high-speed turnouts.

Chapter 3 presents the structural type, principle and method for selection, and structural design and stress analysis of special rails in the turnout, and briefs the technical requirements and manufacturing process of the rails for Chinese high-speed railways.

Chapter 4 discusses the design theories and methods of turnout wheel–rail relation, which is a key and core point of the book. Vehicle–turnout system dynamics is a main tool for assessing the impacts of irregularities and the theoretical basis for the low dynamic force design of turnout structure, analysis of the cause of inordinate dynamic indicators during the passage of train in the turnout, and formulation of technical indicators related to turnout manufacturing, assembly, laying, and maintenance. This chapter also introduces the change rule of wheel–rail contact relation with train motion in the turnout area, 3D elastic body multi-point rolling contact analytical theory in the turnout, vehicle–turnout dynamics, and its application in assessment. Besides, the design methods for dynamic parameters based on single DOF wheelset is introduced in this chapter to help the designers to understand the impact rule of wheel–rail relation design on riding quality.

Chapter 5 tells about the track composition in the turnout area and its rule of longitudinal distribution, rational arrangement of track stiffness of the fastenings, and the methods and engineering methods for homogenous stiffness design along the track.

Chapters 6 and 7 are dealing with the calculation theories and design methods of high-speed turnouts in trans-sectional CWR line under the action of longitudinal temperature force. Specifically, Chapter 6 tells about the structural characteristics, analytical theories and methods and stress deformation rule of CWR turnouts, and the design verification method and layout principle for CWR turnouts in the design of trans-section CWR lines.

Chapter 7 introduces the rules of longitudinal interaction between CWR turnouts and bridges, and the rules of dynamic interactions of train–turnout–bridge system, and proposed recommended design requirements on relative position of the sleeper and bridge beam structure when laying a CWR turnout on bridge.

Chapter 8 introduces the traction and conversion devices and conversion principle for the conversion in the main/diverging line of the turnout, design methods for switching force and throws, as well as applicable engineering measures for reducing the switching force and easing scant displacement in Chinese high-speed railways.

Chapter 9 introduces the design methods for baseplates, fastenings, turnout sleepers, and other sub-rail components for turnouts.

Chapter 10 describes indoor and outdoor test technologies for justifying the above theories and methods.

Chapter 11 discusses the manufacturing equipment and process of high-speed turnouts, key production process for rails and baseplates, and assembly and acceptance technologies for high-speed turnouts.

Chapter 12 introduces the technologies for transportation, laying, inspection, and acceptance of high-speed turnouts.

Chapter 13 analyzes the impacts of poor wheel–rail relation, geometry and defective parts on the riding safety, and quality of high-speed turnout in the turnout with the example of several typical turnout defects occurred in the operation of Chinese high-speed railway, and provides with related improvement measures which may provide reference for maintaining personnel in analyzing the cause and formulating countermeasures in the future.

Chapter 14 introduces the management systems and maintenance standards of Chinese high-speed railways and turnouts, inspection and monitoring technology, and machines and methods for maintenance and repair. At last, the application and future prospect of certain leading technologies, such as RMAS, LCC, and informatization technology, in the management of Chinese high-speed turnouts are introduced.

This book is co-sponsored by “Critical theory and methods for the inspection of high-speed railway track structures” (U1234201), a key project supported by the joint fund for the fundamental research of high-speed railways of National Natural Science Foundation of China, and “Research on key scientific problems on operational safety of high-speed railway track structures” (51425804), a product supported by National Natural Science Funds for Distinguished Young Scholar.

My thanks go to Mr. Li Zhenting of Shanghai Railway Bureau, Mr. Wu Xishui and Mr. Liu Bingqiang of High-speed Railway Department, Infrastructure Division, Transportation Bureau of China Railway Cooperation, Mr. Wang Shuguo, assistant researcher of CARS for their contribution of a great number of references, field cases, and relevant data.

The compilation of the book is supported by my staff of railway engineering group of Southwest Jiaotong University. I am almost indebted to my PhD/graduate students: Dr. Xu Jingmang for his study on 3D elastic body multi-point rolling contact theory in the turnout zone, Dr. Chen Xiaoping for his research on homogenization of turnout stiffness, Dr. Chen Rong for his efforts on dynamics of train-turnout-bridge system, Dr. Yang Rongshan for the study on turnout-bridge longitudinal interactions, Dr. Ren Juanjuan for the study on turnout-bridge longitudinal interaction on tracks with longitudinally coupled base slabs, Dr. Cai Xiaopei for the analysis on turnout conversion, Mr. Zhou Wen for the analysis on turnout plane line type, Dr. Quan Shunxi for the dynamic analysis on track geometry irregularity in turnout zone, Dr. Cao Yang for the analysis on turnout plane line type, Dr. Zhao Weihua for the analysis on wheel–rail relation at the crossing, and Dr. Ma Xiaochuan for his analysis on turnout dynamic simulation. In addition, my postgraduate students, Zhang Mengnan, Sun Hongyou, etc. have made a great deal of effort in reviewing the text, drawing, tabulating, equation editing and translating, and proofreading.

This book will be published both in English and Chinese at the same time. I would like to express my gratitude to Southwest Jiaotong University Press and Elsevier B.V. of the Netherlands

for their help in the publishing work. My gratitude will also be given to my peers in railway engineering and relevant publishers who have helped and concerned about this book.

I would like to mention in particular Doctor Chen Rong, Doctor Zhao Caiyou and Doctor Xu Jingmang who helped a lot in proofreading the English draft.

The independent development of high-speed turnouts is relatively new in China. Therefore, relevant design theories and maintenance technologies need to be improved gradually in practice. Certain researches are still on the way. The book, which will be upgraded in the future, may not be satisfactory to every reader. Limited by time and knowledge of the author, the text, particularly some of the English expressions, might be inaccurate, or may not be rendered in-depth or in detail. For any inaccuracy, please oblige me with your valuable comments and active discussions.

Wang Ping

Southwest Jiaotong University,

Chengdu, China

2015

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TYPES AND STRUCTURE

A turnout is a trackside installation enabling railway vehicles to change tracks or crossover another track. It is an essential part of a railway track system. In fact, a turnout is an integrated system. It is difficult to maintain and critical to riding speed and safety. In addition, it is regarded as the weak point of a line and a main concern in high-speed railway (HSR) construction [1,2].

1.1 MAIN TYPES [3]

High-speed turnouts refer to the turnouts for 250 km/h and above in the main line. Among these turnouts, those for 160 km/h and above in the diverging line are known as high-speed turnouts in the diverging line, which have greater numbers and longer lengths than other turnouts.

1.1.1 COMPOSITION

A high-speed turnout is composed of rails, sub-rail foundations (e.g., fastenings, ties, and ballast or ballastless bed), conversion equipment, monitoring system, turnout heaters, and track stiffness transitions at two ends [4].

It is generally designed as a simple type crossing owing to the structural complexity, that is, consisting of a set of switches, crossing, and transition lead curve.

1.1.2 CLASSIFICATION

Main types:

1. Turnouts for 250 km/h and 350 km/h in the main line.
2. Turnouts for 80 km/h, 120 km/h, 160 km/h, and 220 km/h in the diverging line.
3. Turnouts in the main line, the crossover, and the connecting line (by function). The turnout in the main line lies at the throat of a station, enabling trains to access the receiving-departure track through the main line. The turnout in the crossover, as shown in Figure 1.1, lies away from the station throat and enables a train to switch routes between the up line and the down line. The turnout in the connecting line also lies outside the station throat and enables a train to change tracks between two HSR lines. The three types of turnouts are for 80 km/h, 80–160 km/h, and 120–220 km/h in the diverging line, respectively.

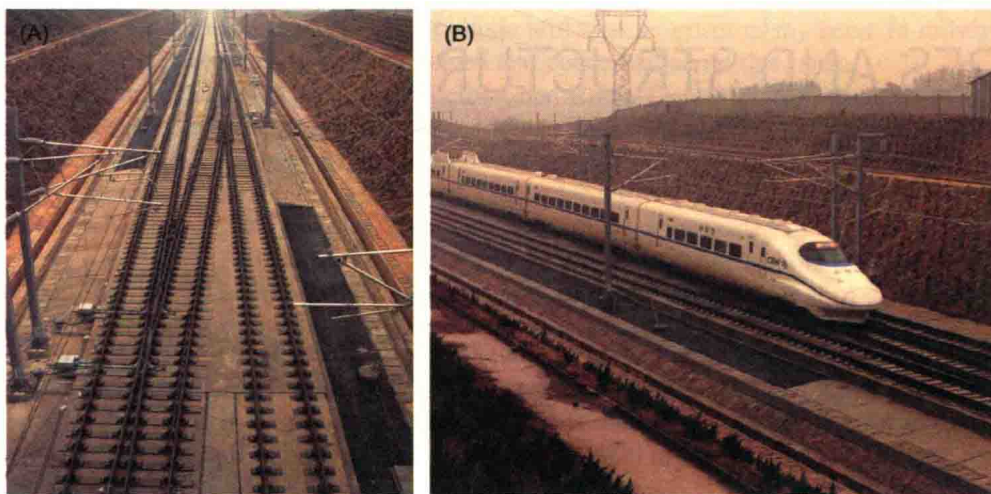


FIGURE 1.1

(A) Layout of crossover turnouts. (B) An EMU train changing tracks between the up line and the down line.

4. Ballasted turnouts and ballastless turnouts (by subfoundations). Ballasted turnout uses prestressed concrete ties; ballastless one may use embedded concrete ties or slabs. The two turnouts use the same rails.
5. No. 18, No. 30, No. 42, and No. 62 turnouts, etc. (by turnout number). In France and Germany, a high-speed turnout in the diverging line may have a nonintegral number (e.g., No. 39.113) when being laid in a line with varied track distances.
6. Turnouts with swing nose crossings or fixed crossings (by crossing type). All high-speed turnouts in China are provided with swing nose crossings, whereas in other countries, fixed crossings may be used in some turnouts for 250 km/h.
7. Turnouts with a rail cant of 1:40 or 1:20 (by rail cant). The rail cant of high-speed turnouts is 1:40 in both China and Germany, and 1:20 in France.
8. In addition, 60 kg/m rails, standard gauge, and trans-sectional continuously welded rail (CWR) track are quite common in HSRs, so high-speed turnouts are not classified by rail type, gauge, or joint.

Normally, a high-speed turnout is named after the combination of the rail type, the permissible speed in the main line, the sub-rail foundation, and the turnout number, such as No. 18 ballastless simple turnout with 60 kg/m rails for 350 km/h.

1.2 TECHNICAL REQUIREMENTS

A high-speed turnout is an intricate system. It involves the technologies of track structures (rails, fasteners, ties, and ballasted and ballastless bed, etc.), interface technologies of CWR track on embankments and bridges, the wheel–rail relation, electrical conversion, and track circuit, as well as interdisciplinary technologies of precision machinery manufacturing, mechanized track laying and maintenance, control survey, and informatized management [5].

1.2.1 EXCELLENT TECHNICAL PERFORMANCE

A high-speed turnout shall meet the following technical requirements:

1. High speed

It shall have the same speed in the main line of the turnout as in a common railway section, and have a relatively high speed in the diverging line without affecting normal traffic. For safety considerations, the design speeds in the main line and the diverging line shall have safety margins of 10% and 10 km/h, respectively.

2. High safety

For a high-speed turnout, the following requirements shall be satisfied when an Electric Multiple Unit (EMU) train travels at the design speed in the main/diverging line:

- a. Indicators such as load reduction rate and derailment coefficient are the same as in a section
- b. The spreads of switch rails and swing nose rails are sufficient to avoid collision against wheels
- c. The conversion equipment functions normally, so that no defective insulation area (where all traffic lights are red) or signal abnormalities occur
- d. Moveable rails are locked securely, so that no derailment takes place in case any inclusion appears in the closed zones, or the switch rod is distorted by the inclusion
- e. The monitoring systems are integrated to identify faults and hidden dangers degrading riding safety, such as abnormal conversion, inordinate closure, and rail fracture; and
- f. Turnout heaters are provided in cold areas to prevent snow or ice accumulating at the switches and crossings in cold weather, so as to ensure normal operation.

3. High stability

When an EMU train travels at a normal speed in the main/diverging line of turnouts, the train will not shake significantly, thus providing the same passenger comfort in turnouts as in sections. The lateral carbody acceleration shall not have first-order inordinateness (i.e., 0.6 m/s^2 as per the criteria of the planned preventive maintenance for Chinese HSR) during the passage of comprehensive inspection trains or track geometry cars in the turnout.

4. Excellent comfort

The same passenger comfort can be offered vertically as in a section, and no “jerking” (which may occur at bridge ends) occurs when an EMU train travels at a normal speed in the main/diverging line, nor does any inordinate vertical vibration appear due to inhomogeneous track integral stiffness in the turnout area. The vertical carbody acceleration shall not have first-order inordinateness (i.e., 1.0 m/s^2 as per the criteria of the planned preventive maintenance for Chinese HSR) during the passage of comprehensive inspection trains or track geometry cars in the turnout.

5. High reliability

HSRs are in closed operation in the daytime, and occupied for “skylight” maintenance at nighttime. Therefore, high-speed turnouts shall have high reliability, without conversion faults or invalid closure detections, etc.

6. High smoothness

All HSR track structures, including high-speed turnouts, shall have high performance in smoothness. Geometric deviation (alignment, longitudinal level, etc.) and closure clearances of a turnout shall be acceptable. The scant switching displacement shall not affect the deviation of the gauge, and structural irregularities induced by wheel-rail relation shall not affect riding quality.