

# Research on Key Technologies of Intelligent Steer-By-Wire System

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**Abstract:** With the deep integration of new energy vehicles and intelligent network technology, the steer-by-wire system, as the core execution unit of the steer-by-wire chassis<sup>1</sup>, completely breaks the structural shackles of traditional mechanical steering and realizes the electronic, precise and intelligent transmission and execution of steering instructions<sup>2</sup>. Based on the Chinese latest national standard of GB 17675-2025 'Basic Requirements for Automobile Steering System'<sup>3</sup>, this paper systematically expounds the structural composition, working principle and core key technologies of the steer-by-wire system, deeply compares and analyzes the performance differences between the steer-by-wire system and the traditional steering system, analyzes the functional safety redundancy design and fault handling mechanism of the system, verifies the technical advantages with the measured data of the industry, sorts out the current technical application pain points and industrial development trends, and provides theoretical reference and technical support for the technical iteration, engineering application and standardized landing of the steer-by-wire system.

**Keywords:** Intelligent wire control chassis, steering by wire, electrical signal control, functional safety, redundant design, autonomous driving.

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## 1. Introduction

Steer-by-wire technology was first applied in the aerospace field. It was gradually introduced into the automotive industry at the end of the 20th century. After more than 20 years of technical iteration, it has moved from concept research and development to mass production. The official release of the new Chinese national standard GB 17675-2025 in 2025 has completely improved the regulatory standard system of the steer-by-wire system [3], and clarified the performance requirements, test methods and safety specifications of the full power steering, marking that China's steer-by-wire technology has officially entered the stage of standardization and large-scale application. As the core component of chassis lateral control, Steer-by-Wire (SbW) is an indispensable key technology carrier for high-level automatic driving. Compared with the traditional steering system, steer-by-wire realizes the global adjustment of steering parameters, active fault tolerance, vehicle space optimization and lightweight energy reduction through the physical decoupling of steering wheel and steering mechanism. It perfectly adapts to the dynamic characteristics and intelligent driving control logic of new energy vehicles, and has become the core direction of industry technology upgrading.

## 2. General Overview of Steer-By-Wire System

### 2.1. Technical Definition and Core Features

According to GB/T 35360-2017 'Terms and Definitions for Automotive Steering Systems', the steer-by-wire system is a new type of steering system that completely relies on electric energy manipulation and abandons mechanical transmission links. The core feature is that the steering wheel and the wheel steering mechanism are decoupled, and there is no traditional steering column, mechanical transmission shaft and other connection structures. The driver's steering intention and road surface feedback information are completely transmitted in

two directions through electrical signals, and the command analysis, strategy operation and execution drive are completed based on the electronic control unit<sup>4</sup>.

Different from the technical mode of electric power steering (EPS) which only assists and retains the complete mechanical transmission link, the steer-by-wire system realizes the full electrification control of the steering system. All steering actions, road feeling feedback and fault protection are completed independently by the electronic control system, with three core characteristics. First, all-electric signal transmission, no physical torque transmission, control instruction transmission without mechanical lag; second, the parameters are adjustable in the whole domain, and the steering ratio, road feel strength and response speed can be dynamically adjusted according to the speed, working condition and driving mode. Third, high safety redundancy is controllable. Relying on multi-module redundancy design and real-time fault diagnosis, it can realize fault degradation operation, eliminate the risk of steering failure, and meet the highest level requirements of ISO 26262 automotive functional safety ASIL D5.

### 2.2. The Overall Architecture and Composition Module of The System

The steer-by-wire system adopts a modular hierarchical architecture, which can be divided into two categories: core function module and auxiliary support module. The core function module includes steering wheel module, main controller (ECU) and steering execution module, which is the core carrier to realize steering control. The auxiliary support module includes a fault processing system, a redundant power supply system, a CAN bus communication system, and a sensor sensing system. It mainly provides a comprehensive guarantee for the stable and safe operation of the system. The overall architecture has no mechanical hard connection, and each module works together with the bus protocol through electrical signals.

### 2.2.1. Steering Wheel Module (Intention Input and Road Feeling Feedback Unit)

The steering wheel module is the human-computer interaction core of the steer-by-wire system. It is mainly responsible for the driver's steering intention acquisition and analog road feel feedback. The hardware includes the steering wheel assembly, the angle-torque integrated sensor, the road feel motor, the reducer and the signal conditioning circuit. The module collects the steering wheel angle, angular velocity and operating torque in real time through high-precision sensors, converts the mechanical rotation operation into digital signals, and transmits them to the main controller through redundant CAN bus to complete the steering intention input.

### 2.2.2. Main Controller (Core Operation and Decision-Making Unit)

The main controller is the core of the system's operation and decision-making. In order to meet the requirements of the ASIL D functional safety level, the industry generally adopts a dual-redundant architecture with dual-channel signal acquisition, cross-checking and fault self-diagnosis capabilities. During the working process, the controller synchronously receives the steering wheel operation signal and the angle feedback signal of the execution module, and links the vehicle CAN network to obtain the vehicle parameters such as vehicle speed, yaw rate and braking state. Relying on the built-in algorithm, the steering intention analysis and control strategy operation are completed. At the same time, the controller monitors the running state of each module throughout the whole process, which can identify anomalies in time and trigger fault protection mechanism to ensure the stable operation of the system.

### 2.2.3. Steering Execution Module (Action Execution and Feedback Unit)

The steering execution module is the final execution carrier of the vehicle steering action, which directly determines the steering accuracy and response speed. It is mainly composed of steering execution motor, motor controller, rack and pinion mechanism, angle and displacement sensor. It also supports multi-phase redundant drive, and single circuit fault can still work normally with higher reliability. The module receives the precise angle command of the main control, drives the motor through vector control and closed-loop PI control, and drives the rack mechanism to complete the steering action. At the same time, the high-precision sensor collects the wheel angle and speed data in real time and transmits them back to the main control to form a closed-loop control to effectively suppress the steering deviation. The measured data show that the steering angle tracking error of the main stream steer-by-wire system can be controlled within  $2^\circ$ , the response speed is more than 30% higher than that of the traditional EPS system, and the advantages of steering dynamic performance and control accuracy are significant.

### 2.2.4. Auxiliary Support Module

The auxiliary support module is an important support for the safe and reliable operation of the system. It is mainly composed of three subsystems: redundant power supply, fault handling and redundant CAN communication, which directly determines the fault tolerance and working condition adaptability of the system. The redundant power supply adopts a dual-channel DC / DC with a low-voltage battery backup architecture. The fault handling system has real-time monitoring, fault classification determination, degraded

operation and fault early warning functions, which can accurately identify sensor, motor, communication and power failure. According to the fault level, the corresponding safety strategy is implemented to ensure the controllable operation of the steer-by-wire system under complex working conditions and fault conditions, and provide a guarantee for the steering safety of the vehicle.

## 2.3. System Work Complete Process

The steer-by-wire system adopts the closed-loop working logic of 'perception-operation-execution-feedback-calibration'. There is no mechanical intervention in the whole process, and the workflow is highly intelligent and accurate, as shown in Figure 1.

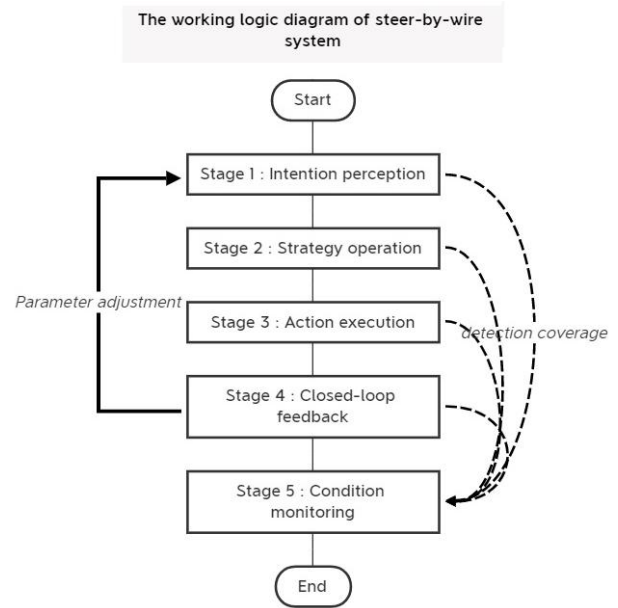


Figure 1. The working logic diagram of steer-by-wire system

The first stage is intention perception. The steering wheel module sensor collects the driver's angle and torque signals in real time, converts them into digital signals and uploads them to the main controller through the redundant CAN bus. The second stage is the strategy operation. The main controller integrates vehicle parameters such as vehicle speed, body posture and road condition, and calculates the optimal wheel angle and road feeling feedback torque through the core algorithm to generate precise control instructions. The third stage is action execution. The main controller sends instructions to the steering execution module, and drives the motor to drive the wheel to complete the steering action. The fourth stage is closed-loop feedback. The wheel angle sensor returns the actual steering data in real time. The controller compares the deviation between the command value and the actual value, and corrects the control parameters in real time. The fifth stage is condition monitoring. The fault processing system monitors the operation status of each module throughout the whole process, realizes real-time fault diagnosis and fault-tolerant control, and ensures the stable operation of the whole system.

## 3. Key Technologies of Steer-By-Wire System

### 3.1. Variable Steering Ratio Adaptive Control Technology

The variable steering ratio technology is the core

differentiation technology of the steer-by-wire system, and it is also the core advantage that it is superior to the traditional steering system. The steering ratio of traditional mechanical steering and EPS system is a fixed value, which can not adapt to the control requirements of different vehicle speeds and different working conditions. There is an inherent contradiction between low-speed steering and high-speed

steering sensitivity. The steer-by-wire system can realize the adaptive variable steering ratio of the vehicle speed based on the electronic controllable characteristics. The steering ratio can be dynamically adjusted in the range of 10: 1-20: 1, which perfectly balances the low-speed maneuverability and high-speed stability. The characteristics of the three operating conditions are shown in Figure 2.

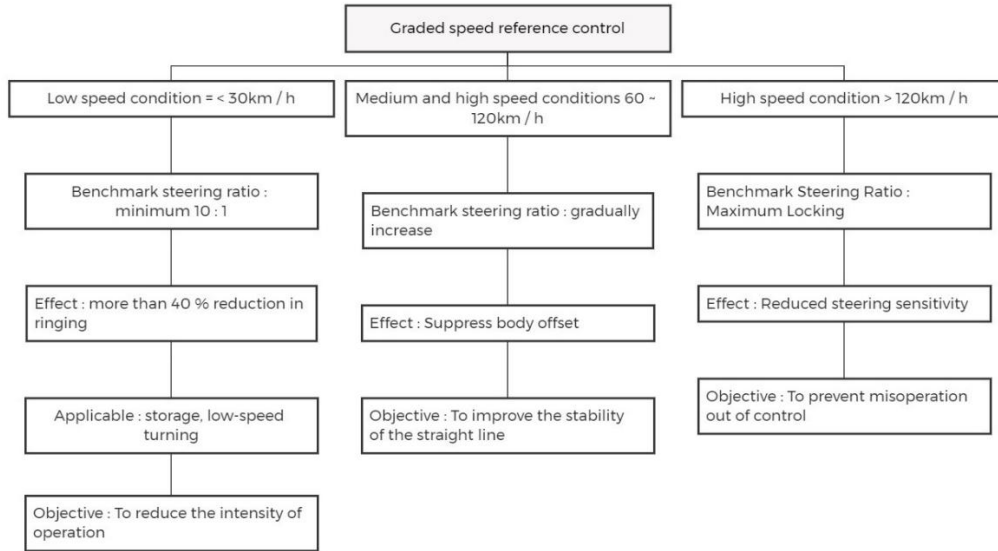


Figure 2. Comparison of steering characteristics of steer-by-wire system under three working conditions

The steer-by-wire system relies on the above control, and the dynamic fine-tuning compensation mechanism achieves fine control. It mainly includes three parts: adjusting the lateral acceleration and road adhesion input parameters,

adapting to wet and curved conditions, and correcting the output to avoid insufficient and excessive steering, shown in Figure 3.

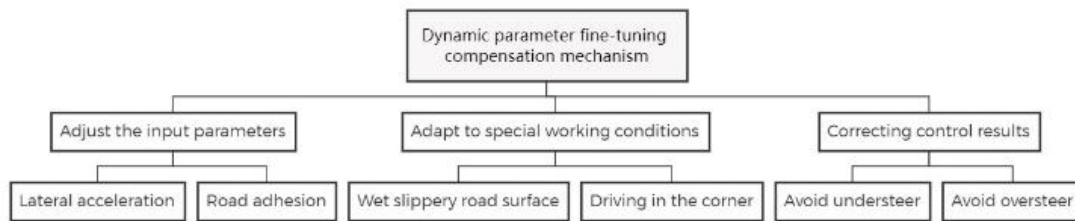


Figure 3. Dynamic parameter fine-tuning compensation mechanism

### 3.2. Simulated Road Feeling Accurate Feedback Technology

Since the steer-by-wire system cancels the mechanical connection, the steering wheel cannot obtain road feedback through the physical structure, so accurately simulating the real road feeling is the core technology to ensure the driving experience. Through the closed-loop control technology of the road sense motor, combined with the rack force observation algorithm and the speed-road condition coupling algorithm, the steer-by-wire system accurately restores the feedback information such as road bumps, steering resistance, and tire grip status.

### 3.3. Multi-redundant Security Design Technology

The physical decoupling structure leads to no mechanical backup of the steer-by-wire system. Once the electronic system fails, it is easy to cause the risk of steering failure. Therefore, the multi-redundancy design is the core key for the system to meet the ASIL D functional safety level, and it is also the core technical index required by the Chinese national standard GB 17675-2025. At present, the mass production

steer-by-wire system adopts a full-link multi-redundant architecture, covering the whole chain of power supply, communication, controller, actuator and sensor.

The redundant power supply adopts the scheme of dual DC / DC independent power supply + low-voltage battery backup. When the single power supply fails, the backup power supply can seamlessly take over the power supply without power supply interruption. The communication redundancy is transmitted independently by the main and secondary CAN bus. When the single bus is disconnected and the signal is interfered, the other bus ensures the normal transmission of the instruction. The redundancy of the controller adopts the dual-chip mutual inspection architecture. The main controller and the deputy controller are synchronized and cross-checked. When the main controller fails, the deputy controller immediately takes over the work. Actuator redundancy adopts multi-phase motor backup design, and any two-phase fault of six-phase motor can still maintain normal driving. The sensor redundancy adopts two-sensor signal comparison acquisition to avoid abnormal data caused by single sensor failure. The measured data show that the steering-by-wire system equipped with full-link redundancy design will not lose steering function due to a single electronic fault, and can still

meet the steering performance requirements specified in the Chinese national standard under fault conditions.

### 3.4. High Precision Closed-Loop Control Technology

The steer-by-wire system adopts a three-stage closed-loop control architecture, including a current loop, a speed loop, and a corner loop to achieve high-precision and high-response control of the steering action. The current loop is used as the underlying control to adjust the output current of the motor in real time, suppress the torque fluctuation and ensure the stability of the power output. The speed loop is a middle-level control, which accurately controls the running speed of the motor to avoid too fast or too slow steering action. The steering angle loop is the top-level control. By comparing the deviation between the actual steering angle of the wheel and the target steering angle, the control instructions are corrected in real time to achieve accurate tracking.

### 3.5. Intelligent Fault Diagnosis and Fault-Tolerant Control Technology

The steer-by-wire system is equipped with a full-time domain fault diagnosis algorithm, which can monitor various faults such as sensor signal abnormality, motor overload, communication interruption, power supply undervoltage, and execution stagnation in real time, and realize millisecond-level identification and classification of faults. The system divides the fault into three levels: slight, moderate and severe.

Corresponding to different fault-tolerant strategies, it ensures that the vehicle can park safely and completely eliminate the potential safety hazards of complete steering failure. According to the test requirements of GB 17675-2025 standard, the system can still complete more than 24 times of 8-character steering under the conditions of control transmission failure, power supply failure and energy transmission failure. The steering control force and steering time meet the requirements of intact state performance, and the fault controllability reaches the highest standard in the industry.

## 4. Comparative Analysis of Performance Between Steer-By-Wire System and Traditional Steering System

The automobile steering system has undergone four generations of technology iterations: mechanical steering (MS), hydraulic power steering (HPS), electric power steering (EPS), and steer-by-wire (SbW). As the fourth generation of steering technology, steer-by-wire has completely broken through the structure and performance bottlenecks of the first three generations of products. It has all-round advantages in safety, maneuverability, economy, space utilization, and intelligent adaptability. The core performance comparison of each system is shown in the following table 1.

**Table 1.** Comparative analysis of performance between steer-by-wire system

Performance	Indicators Mechanical steering system	Hydraulic power steering system	Electric power steering system	Steer-by-Wire steering system
Mechanical structure	Complete mechanical transmission link	Mechanical link + hydraulic power	Mechanical link + motor power	Without mechanical connection, all electrical architecture
Steering ratio characteristics fixed	Non-adjustable fixed	Non-adjustable	Small variable	Global speed adaptive adjustable
Response delay	80~120ms	50~80ms	20~30ms	≤ 10ms
Control precision	Error≥5°	Error≥4°	Error≥3°	Error≤2°
Safety redundancy ability	No redundancy, direct failure of mechanical failure	No electrical redundancy, hydraulic failure	Local power redundancy	Full link multiple redundancy, fault control
Lightweight level	Heavy weight, cumbersome structure	Heavy weight, hydraulic component redundancy	Lightweight moderate	Weight loss of 15 % ~ 25 %
Energy consumption level	Mechanical loss, high energy consumption	Hydraulic overflow loss, high energy consumption	On-demand assistance, low energy consumption	On-demand power supply, comprehensive energy efficiency increased by more than 50 %
Intelligent adaptation	Without intelligent adaptation ability	Can not adapt to intelligent driving control	Can only adapt to the primary auxiliary driving	Adaptation L3-L4 high-level automatic driving

### 4.1. Security Performance Advantages

The traditional steering system retains the steering column and other mechanical structures. When the vehicle is in a frontal collision, the engine compartment components are easy to squeeze the steering column, causing the steering column to invade the cab backward, causing serious impact damage to the driver's chest and torso. It is one of the main causes of driver injury in traffic accidents. The steer-by-wire system completely eliminates rigid structures such as steering columns and mechanical transmission shafts, eliminates the risk of secondary collision damage from the root, and greatly improves passive safety performance.

### 4.2. Manipulation and Comfort Performance Advantages

The steer-by-wire system completely solves the performance contradiction of the traditional steering system's 'low-speed bulky, high-speed sensitive' through variable steering ratio and adaptive road feeling technology. Under low speed conditions, the steering is light and flexible, which greatly reduces driving fatigue; under high-speed conditions, the steering is stable and accurate, which effectively suppresses the body jitter and deviation. At the same time, the system can filter the steering wheel jitter caused by the fine and bumpy road surface and the tire vibration, avoid the

problem of road clutter and noise interference of the traditional steering system, and significantly improve the driving comfort. Under the extreme control conditions, the vehicle handling stability and extreme traffic capacity are greatly improved, which fully meets the high-precision and high-reliability requirements of high-level autonomous driving for lateral control.

### **4.3. Lightweight and Energy Saving Advantages**

The steer-by-wire system eliminates a large number of mechanical and hydraulic components such as steering column, universal joint, hydraulic pipeline and hydraulic oil pump. The system structure is highly integrated and modular. The overall weight is 15 % to 25 % lower than that of the traditional EPS system, and the quality is greatly optimized. At the same time, the system adopts the working mode of on-demand power supply and on-demand drive, without the continuous overflow loss of the traditional hydraulic system. The comprehensive working efficiency of the system is more than 54.3 % higher than that of the traditional steering system, and the energy utilization rate is greatly optimized. In addition, the number of parts is greatly reduced, which reduces the cost of parts procurement, assembly and maintenance, and effectively controls the production cost and maintenance cost of the whole vehicle.

### **4.4. Space and Architecture Adaptation Advantages**

The traditional mechanical transmission structure occupies a large longitudinal space between the cabin and the cab, which limits the optimization of the vehicle layout and the expansion of the cabin space. The steer-by-wire system has no mechanical transmission link and flexible structural layout. The steering wheel module and execution module can be freely arranged according to the design requirements of the vehicle architecture, which greatly releases the front space of the cockpit and provides sufficient space for the intelligent layout of the cockpit, the optimization of the airbag and the modular design of the chassis. At the same time, the modular and platform-based design of the system can realize cross-model general-purpose, adapt to multiple types of models such as cars, SUVs, commercial new energy vehicles, greatly shorten the development cycle of models and reduce the cost of platform development.

## **5. Technology Development Trend and Industry Prospect**

### **5.1. High Integration and Integrated Development**

In the future, the steer-by-wire system will develop in the direction of 'steering-braking-driving' chassis integrated integration, breaking the independent control mode of a single subsystem, realizing the chassis global electronic control collaborative control, greatly improving the vehicle control coordination and stability of high-level automatic driving, and realizing the high integration, integration and platform of the chassis system.

### **5.2. Intelligent Algorithm**

Relying on the continuous upgrading of artificial intelligence, big data and vehicle computing power, the steer-

by-wire control algorithm will realize intelligent iteration<sup>6</sup>. Through machine learning massive road condition data, the road feeling simulation, steering ratio adaptation and fault prediction algorithm under complex working conditions are optimized, and the control accuracy and road feeling reality under extreme road conditions and complex scenes are improved.

### **5.3. Localization and Large-Scale Popularization of Low Cost**

With the technological breakthroughs of China's domestic automobile enterprises and parts enterprises, the localization rate of core components such as steer-by-wire core chips, high-precision sensors, and multi-phase motors continues to increase, the ability of independent control of the supply chain continues to increase, the cost of system mass production will gradually decline, and the industrial scale effect will continue to highlight<sup>7</sup>.

### **5.4. Safety Standard System Continues to Improve**

The steer-by-wire standard system with GB 17675-2025, DIN 70065 and ISO 26262 as the core will continue to iterate. The fault test conditions, performance determination indicators and functional safety requirements will be further refined. The test and verification system covering the whole scene and the whole working condition will be gradually improved, which will provide solid support for the standardization, safety and standardization of steer-by-wire technology and promote the high-quality development of the industry<sup>8</sup>.

## **6. Conclusion**

The steer-by-wire system is the core key hardware of intelligent steer-by-wire chassis and high-level automatic driving, and it is the inevitable trend of vehicle steering technology iteration. The system relies on mechanical structure decoupling, all-electric signal transmission, multiple safety redundancy and high-precision closed-loop control technology to break through the structural limitations and performance shortcomings of traditional steering systems<sup>9</sup>. It has significant advantages in driving safety, control accuracy, driving comfort, lightweight energy saving and intelligent adaptability, which is highly consistent with the development direction of electrification, intelligence and lightweight of new energy vehicles.

Based on the latest Chinese standards and measured data, this paper systematically explains the architecture mechanism and core technology of the steer-by-wire system, quantitatively compares the performance differences of the four-generation steering system, and predicts that it will iterate in the direction of integration, algorithm intelligence, localization and scale, and industry standardization<sup>10</sup>. With the breakthrough of technology and the improvement of standards, steer-by-wire will gradually replace the traditional steering structure, become the standard configuration of intelligent vehicles, and help the domestic intelligent connected vehicle industry and high-order automatic driving to land on a large scale.

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