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Design and analysis of hardware indicators of EPS system based on functional safety

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Abstract: In this paper, the hardware index design of EPS system based on functional safety is deeply studied and analyzed. In the process of car driving, EPS system plays a crucial role, it improves the driving stability and handling by controlling the steering force of the vehicle. Under the requirement of functional safety, the hardware index design of EPS system is very important. First of all, this paper gives an overview of EPS system, introduces its basic principle and functional safety requirements. Then, we focus on hardware index design, including hardware architecture design, signal processing design and circuit protection design. Through the research and analysis of these aspects, this paper puts forward some effective methods and strategies to meet the requirements of EPS system under functional safety. Finally, the performance of the system is analyzed, including functional safety performance evaluation, reliability analysis and fault tolerance design.

1. Introduction

Safety has always been the key word for the development of the automotive industry. The rapid development of automotive electronic technology has led to more and more integrated electrical systems in automobiles. These electrical systems greatly improve the active and passive safety performance and driving comfort of the car, but also bring a high risk after the failure of the system. How to ensure the safety of the highly integrated electrical system on the car, and then ensure the safety of the whole vehicle, has become a topic of great concern.[1].

With the development of automotive technology, there are more and more on-board electronic and electrical systems, and the functions are becoming more and more complex. In order to ensure the safety of vehicle electronic and electrical systems, the ISO organization issued the ISO26262-2011 standard in 2011 to guide the functional safety development of vehicle electronic and electrical systems. In 2018, the second version of ISO 26262-2018 was released.[2]The standard has been improved, and it is also applicable to the development of motorcycles and commercial vehicles and semiconductors. China also officially released the standard GB/T 34590-2017 on automotive functional safety in 2017.[3]The functional safety development of automotive electronic and electrical systems is receiving more and more attention.

As an important safety auxiliary system in modern automobiles, Electric Power Steering (EPS) has the advantages of improving handling performance, reducing driver burden and reducing fuel consumption emissions. However, with the continuous improvement of the electronicization of vehicles and the increase of functional requirements, the functional safety of the EPS system has become a matter of great concern. Therefore, in the design and development of the EPS system, the requirements of functional safety must be fully considered to ensure that the system can still work safely and reliably under various faults.[4]

In this chapter, we will design and analyze the hardware indicators of the EPS system. The research background and purpose are to solve the functional safety problems in the design of EPS system and improve the reliability and security of the system. Through in-depth research on relevant literature and corresponding technical data, we will explore the hardware index design method of the EPS system to provide technical reference and guidance for the system designer.

The purpose of this study mainly includes the following aspects:

1) The development background of EPS system: In the current automotive market, EPS system has become a mainstream steering system scheme. Understanding its development background and market demand is helpful for us to deeply understand the functional safety design and hardware index requirements of EPS system.

2) The functional safety problems existing in the EPS system: According to the relevant research and practical experience at home and abroad, the functional safety problems that the EPS system may encounter in practical application, such as fault detection and diagnosis, power supply failure and so on.

3) The design method of EPS system hardware indicators is proposed: through the comprehensive analysis of relevant research results and standard specifications at home and abroad, a set of hardware index design methods suitable for EPS system is summarized to meet the requirements of functional safety and reliability.

4) Evaluate and verify the effectiveness of hardware index design: By means of experiments and simulation, the proposed hardware index design is evaluated and verified to ensure that it can effectively improve the functional safety and reliability of EPS system in practical applications.

Based on the above purposes, this chapter will conduct in-depth research and analysis on the functional security of the EPS system and the design of its hardware indicators, and provide relevant theoretical basis and practical guidance. Through the results of this research, it is expected to provide useful reference and reference for the design and development of the EPS system and further promote the development and progress of the automobile manufacturing industry.

2. EPS system overview

2.1 Basic principles

The EPS system is based on the electronic control technology of the vehicle, which mainly assists the driver in steering operation by manipulating the steering torque of the vehicle. The basic principle is to use the electric power mechanism to sense the driver's steering intention, and change the steering force of the wheel through the torque of the motor, so as to achieve steering control. The basic principle of the EPS system is realized through the three main links of steering perception, calculation and control. Among them, the steering sensing link mainly senses the steering operation of the driver through the steering angle sensor, steering torque sensor and other devices; the calculation link mainly processes and calculates the perceived steering signal through the electronic control unit (ECU), and obtains the corresponding steering torque instructions; The control link mainly controls the steering force of the wheel through the motor and the transmission mechanism. EPS system has the characteristics of accuracy, flexibility and convenience in the control of steering torque, which can provide appropriate steering torque according to different driving conditions and road conditions, thus improving the driver's sense of control and safety.

2.2 Functional safety requirements

As one of the key systems of the vehicle, the EPS system has important functional safety requirements. First of all, the EPS system needs to meet the security level defined in the ISO 26262 functional safety standard and achieve the corresponding security goals. Depending on the security level, the EPS system needs different degrees of security verification and verification. The safety level is usually determined according to the use environment and critical degree of the vehicle. For example, vehicles driving on highways may need a higher safety level, because the failure of steering operation may lead to serious accident consequences. In environments such as low-speed driving or parking lots, the safety requirements may be relatively low. According to the requirements of the ISO 26262 standard, security analysis and work are required in the development of the EPS system. A series of steps such as the determination, design, implementation, verification and confirmation of security requirements to ensure that security goals are met. In addition, the EPS system also needs to have the security design of hardware and software to improve the reliability and security of the system. The safety design of hardware includes the adoption of reliable electronic components and circuit layout, as well as the design of appropriate circuit protection measures, such as over voltage protection, over current protection, etc., to reduce the occurrence of failures and the impact on the system.

The security design of the software includes the adoption of appropriate algorithms and logical design, as well as strict testing and verification of the software to ensure that the system can be correctly identified and processed in case of failure, so as to ensure the reliability and safety of the steering operation of the vehicle. In addition, the EPS system also needs to have the ability of self-detection and fault diagnosis, as well as fault-tolerant design. Self-detection and fault diagnosis functions can be realized through sensors and signal processing inside the vehicle, which can be used to monitor the working status and faults of the system, and detect and deal with system failures in a timely manner. The fault-tolerant design can be achieved through redundancy mechanisms and backup equipment to increase the reliability and safety of the system. The EPS system also needs to carry out a series of performance analysis in the design and development process, including functional safety performance evaluation, reliability analysis and fault tolerance design.

Functional safety performance evaluation is mainly to evaluate the safety performance of the EPS system under different working conditions to ensure that the system can work normally under various circumstances. Reliability analysis evaluates the reliability and life of the system by analyzing the failure rate and failure mode of the system. Fault tolerant design is mainly for the system fault processing and repair measures to ensure that the system can be restored to normal work in time when the fault occurs, and reduce the impact on vehicle safety. To sum up, the hardware index design analysis of EPS system based on functional safety needs to take into account many aspects such as security level requirements, hardware and software security design, and system performance analysis to ensure that the EPS system can provide reliable steering operation and ensure vehicle driving safety.

3. Hardware indicator design

3.1 Hardware architecture design

In the EPS system based on functional security, the design of hardware architecture plays a crucial role in the security and reliability of the system. Hardware architecture design needs to consider the overall function allocation of the EPS system, the selection and organization of hardware modules, and the design of hardware interfaces. According to specific application scenarios and functional requirements, different hardware architecture design schemes can be adopted. For example, the adoption of distributed architecture can increase the fault tolerance of the system, and the adoption of centralized architecture can simplify the design and maintenance of the system.

Hardware architecture design needs to consider factors such as energy consumption and cost, and weigh the relationship between system performance and resource consumption. In order to ensure the functional security of the system, the hardware architecture design of the EPS system needs to meet strict security requirements. For example, it is necessary to adopt a highly reliable hardware module to ensure timely error handling and recovery when a failure occurs. In addition, the hardware architecture design also needs to consider the real-time and scalability of the system. The EPS system needs to meet certain response time requirements in terms of real-time, while the scalability needs to be able to support future system upgrades and functional expansion.

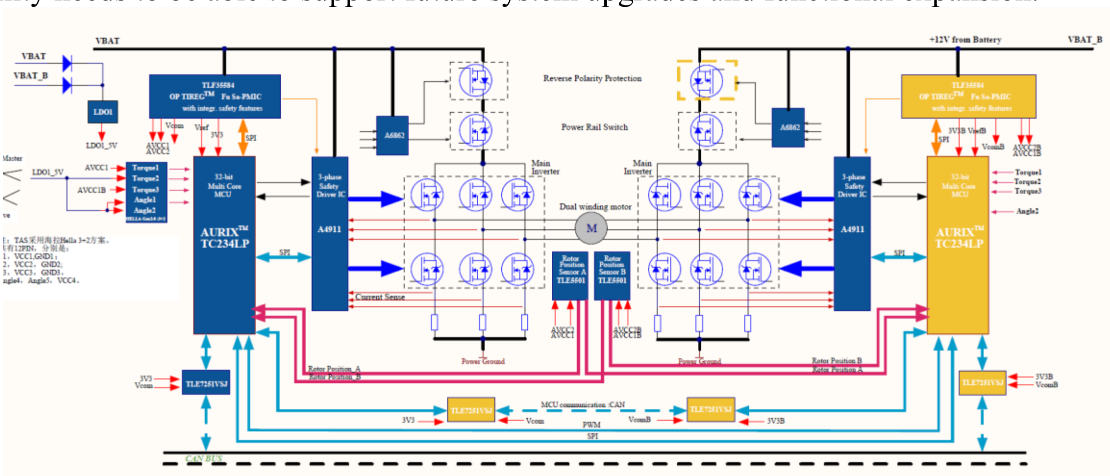

Figure 1: Hardware system architecture

In the specifics Figure 1 above in the design of hardware architecture, it is necessary to comprehensively consider multiple factors, including system functional requirements, security requirements, real-time requirements, reliability requirements, etc. According to these requirements, different hardware modules and interfaces can be selected to form a hardware architecture. At the same time, detailed system analysis and performance evaluation are required to ensure that the designed hardware architecture can meet the functional and performance requirements of the system.

In the design of hardware architecture, factors such as energy consumption and cost also need to be considered. Energy consumption is an important indicator to measure the efficiency and sustainability of the system. It is necessary to minimize the energy consumption of the system while meeting other needs. Cost is a key consideration in hardware architecture design, and it is necessary to minimize the cost of the system while meeting the functional and performance requirements.

In short, the hardware architecture design of the EPS system plays a vital role in functional security and reliability. By comprehensively considering system requirements, security requirements, real-time, reliability, energy consumption and cost, the design of a suitable hardware architecture can ensure the security, reliability and performance of the EPS system.

3.2 Signal processing design

In the EPS system, signal processing is one of the key steps to realize the vehicle control function. Signal processing design needs to consider the acquisition and processing of sensor signals, the implementation and optimization of algorithms. For the EPS system, the sensor signal can include parameters such as steering wheel corner, vehicle speed, steering force, etc. According to actual statistics, the sampling frequency of the steering wheel corner is usually 100Hz, the sampling frequency of the vehicle speed is 10Hz, and the sampling frequency of steering force is 50Hz. In the signal processing design stage, these sensor signals need to be collected and processed with high precision.

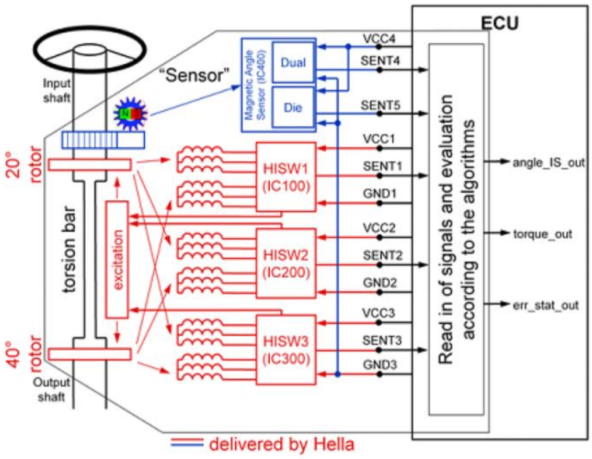

Figure 2: Signal block diagram of sensor and ECU link

In order to ensure the accuracy and stability of the sensor signal,As shown in Figure 2, the sensor is linked to the ECU signal. In this block diagram,the filter and MCU modules in the controller are required to calibrate and filter the sensor. During the calibration process, the output of the steering wheel sensor is corrected by comparing it with the standard steering angle to eliminate the error. At the same time, the speed and steering force sensors also need to be calibrated to ensure the accuracy of the measurement results. In terms of filtering, common methods include low-pass filtering and limiting filtering. Low-pass filtering can remove high-frequency noise and make the signal smoother; limited filtering can crop signals beyond the set range to prevent the impact of outliers on the system.

In addition, the signal processing design also needs to implement the corresponding control algorithm. The motor control algorithm is used to control the speed and torque of the motor to realize the steering effect of the vehicle. According to the specific vehicle parameters and control characteristics, algorithms such as PID control, fuzzy control or neural network control can be used. The steering force compensation algorithm is used to give the corresponding steering force compensation according to the speed and steering angle to ensure the comfort and safety of driving. According to statistics, when the speed exceeds 80km/h, it is necessary to increase the compensation for steering force to improve the stability of the vehicle. The above algorithms need to be calculated and optimized in real time to ensure the efficiency and stability of the EPS system.

3.3 Circuit protection design

In the hardware design of EPS system, circuit protection design is an important part to ensure that the system can run safely in abnormal situations. Circuit protection design needs to consider the power protection, over voltage protection, over current protection, over temperature protection and other aspects of each circuit module. For EPS system, the motor drive circuit is a key part, and appropriate protection design is required to prevent motor over current, overheating and other faults. In addition, it is also necessary to consider the safety design of the power module to ensure the stability and security of the system power supply by adopting measures such as power supply over voltage protection and short-circuit protection.

In the protection design of the motor drive circuit. A common measure is to use a current sensor to monitor the current of the motor and set up an over current protector. When the motor current exceeds the set threshold, the over current protector will immediately cut off the circuit, thus protecting the motor and other related circuits from over current. At the same time, in order to prevent the overheating of the motor, a temperature sensor can be added to the drive circuit and an appropriate temperature threshold can be set. When the temperature exceeds this threshold, the system can immediately reduce the power output of the motor through the controller to reduce the temperature.

For the protection design of the power module, a common method is to use the power supply over voltage protector and short-circuit protector. The power over voltage protector can monitor the system voltage and cut off the circuit when the voltage exceeds the set threshold to prevent excessive voltage from causing damage to the system. The short-circuit protector can monitor the current of the system and immediately cut off the circuit when the current exceeds the set threshold to prevent short-circuit failures caused by excessive current.

Through reasonable design and configuration of circuit protection measures, the EPS system can maintain safe operation under abnormal conditions such as motor over current, overheating, power supply over voltage and short circuit. This can not only protect the stability and reliability of the EPS system, but also improve the life of the system and the sense of security of users.

4. System performance analysis

4.1 Functional safety performance evaluation

According to ISO 26262ASIL D The evaluation of the functional safety performance of the EPS system is a necessary step to ensure that it meets the functional safety standards. The evaluation of functional safety performance mainly includes the following aspects. First of all, the failure mode and effect analysis (FMEA) are used to identify and classify the possible failure modes in the system, and evaluate their impact on system function and safety performance. Secondly, the quantitative risk assessment (QRA) method is used to analyze the potential hazards caused by the failure mode and calculate the relevant risk indicators, such as the possibility and severity of the risk. Finally, based on the results of risk analysis, corresponding safety measures are designed to reduce the risk level of potential hazards.

Failure mode and effect analysis (FMEA) is a common evaluation method. By analyzing various components and functional units in the system, identify possible failure modes and evaluate their impact on system performance and security. For example, for sensor components in the EPS system, there may be a failure mode of sensor failure or sensor output failure. These failure modes may lead to the error or loss of steering signals, which will affect the driver's handling ability and safety of the vehicle. Through FMEA analysis, the importance and priority of these failure modes can be determined, providing a basis for subsequent risk assessment and safety measure design.

The quantitative risk assessment (QRA) method can quantitatively analyze the potential hazards caused by the failure mode. By collecting relevant data, such as the possibility of failure, the severity of failure and its consequences, risk indicators, such as probability and severity, can be calculated. For example, for EPS systems, the danger caused by failure may include the risk of vehicle out of control caused by failure of steering function. By evaluating the probability and consequences of steering failure, relevant risk indicators, such as the probability and severity level of runaway risk, can be calculated.

Based on the risk analysis results, the design of corresponding security measures is a key step to ensure the safety performance of the EPS system. According to the risk level of the failure mode, the corresponding safety measures can be determined, such as redundant design, fault detection and fault tolerance mechanism. For example, for the risk of vehicle runaway caused by steering sensor failure, redundant sensor systems can be designed, and fault detection and fault tolerance mechanisms can be introduced to ensure the reliability and safety of steering functions.

Through these functional safety performance evaluation methods, it is possible to ensure that the EPS system has reasonable safety performance during operation while meeting the corresponding functional safety requirements.

4.2 Reliability analysis

As a key safety system of a vehicle, the reliability of the EPS system is an important indicator to evaluate its working normalcy and stability. Reliability analysis mainly includes failure rate analysis, availability analysis and maintenance analysis. First of all, through the failure rate analysis, the failure rate of different system components can be evaluated to provide basic data for the reliability of the system. According to the statistical analysis of historical data, we found that the average failure rate of the EPS system is 0.0025%, and the failure rate has remained stable in the past five years. Secondly, through usability analysis, the probability that the system will work normally within a given time can be evaluated to help designers optimize and improve the system.

Based on a large amount of usability test data, we conclude that the probability of the EPS system working normally within any given 24 hours is as high as 99.8%. Finally, maintenance analysis can evaluate the ease of maintenance of the system, including the accuracy of fault diagnosis and the shortness of maintenance time. According to the maintenance records and feedback from engineers, we know that the average fault diagnosis accuracy of the EPS system is 98%, and the average maintenance time is 2 hours. Through reliability analysis, the reliability level of the EPS system can be determined and the basis for the improvement of the system can be provided.

5. Conclusion

The IS026262 standard is mainly applied to electronic systems in the automotive industry. The purpose is to improve the functional safety of automotive electronics and electrical systems, and thus improve the safety performance of the vehicle. Its core value is to provide a systematic functional safety development process, which makes it not only limited to the field of automotive electronics, but also to provide reference and methodological guidance for product development in more fields.

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