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Innovative Design of Automotive Steer-by-wire System Based on TRIZ Theory

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Abstract: Due to the removal of the mechanical connection between steering wheel and vehicle wheel, it has become a key issue that how to generate road feel and ensure the safety of wire steering in Steering-By-Wire System. In view of the lack of the road feel and hard to guarantee the security in the process of steer by wire, a new Steering-By-Wire System based on hydraulic is developed to achieve road feel and return-to-center by analyzing the status quo in the use of the technical conflict of TRIZ. This system solves the problem of how to achieve road feel and steering when ECU fails in the process of steer by wire. *Copyright © 2013 IFSA.*

Keywords: TRIZ theory, steer-by-wire system, return-to-center based on hydraulic, Road feel, Steering safety.

1. Introduction

The basic properties of the automobile steering system is to ensure the ideal maneuvering stability when turn the steering wheel under any conditions. With the continuous development of automobile electronic technology, automobile steering system has experienced the following stages: mechanical steering system, hydraulic power steering system, electronically controlled hydraulic power steering system, electric power steering system, Steering-By-Wire System. Steering-By-Wire System (Referred to as the SBW) has first cancelled the mechanical connections between steering wheel to the vehicle wheel. As a result, the vehicle steering characteristics can free design, takes up less space, reduce the complexity of the components effectively, reduced fuel consumption and manufacturing cost [1]. SBW system has been recognized as the future development trend of the automobile steering system.

Although steering by wire system has great development prospects, it is only used for some concept car without large scale of production and installation [2]. The major factors that hinder the development of it are the lack of road feel and insurance of security. It is difficult for drivers to feel the real driving condition and road feel without mechanical connections between steering wheel and vehicle wheel. However the mechanical system has a natural advantage in the road feel [3]. In the aspect of safety, once the Electronic Control Unit (Referred to as ECU) has some problem, the steering by wire system will be completely failed. It is not like electric power steering system, electric hydraulic power steering system and hydraulic power steering system, which can be controlled by human when the motor or

hydraulic system goes wrong [4]. In order to expanding the application of Steering-By-Wire System, we must solve the two difficult problems — road feel and Steering safety.

2. Overview of TRIZ Theory

TRIZ, an acronym for the Theory of Inventive Problem Solving, began in 1946 when Altshuller, a mechanical engineer, began to study 2.5 million high-level patents in the Russian Navy [5]. The core of the invention problem solving theory is the technology evolution theory. According to this theory, technology system has been in evolution and the driving force of evolution is the solution of the contradictions. When the general contradictions in the technology systems are solved, the speed of evolution slows down. The exclusive means to produce mutant is solving the deeper contradictions.

TRIZ has a large amount of systematic, scientific and creative thinking method and the analysis method of the invention problem. After more than half a century of development, TRIZ has become a theory to solve the actual problem of new product development, which consists of nine classic theory system[6]: The Eight Technology System Evolution Laws; The ideal Final Result(IFR); The 40 Inventive Principle; The 39 Engineering Parameters and The Contradiction Matrix; Physical Contradiction And Four Separation Principle; The Substance-Field Analysis Models; The Standard Solution Of The Invention Problem; Algorithm for Inventive-Problem; The Solving Scientific Effect And Phenomenon Knowledge Base.

TRIZ focus on contradictions or trade-offs, without which a design cannot be called an innovation. Detecting contradictions and solving it is the impetus to develop a product in the idealized direction [7]. After having identified abundant contradictions, Altshuller went on to classify them into 39 parameters (now increased to 48), with which the vast majority of contradictions can be described.

Over a period of time Altshuller identified a further level of abstraction from the technical contradictions. He found that, in many cases, the technical contradiction could be presented as two extremes of one feature, which he called a physical contradiction. And when an engineering parameter need to be improved, the other engineering parameters may be worsen, which he called a technical contradiction. In order to guide the solution of contradiction and the innovation design of product, Altshuller proposed 40 common principles on the level of abstraction, and establish corresponding relationship between the 39 engineering parameters and the 40 common inventive principles, which is called the Technical Contradiction Matrix [8]. (As shown in Table 1). The solver can look for the inventive principles to solve the problem in the Technical Contradiction Matrix on the basis of the two contradiction parameters in the system, and solve the problem with the elect inventive principles.

Table 1. The conflict matrix (part).

General engineering parameters		Worsening feature			
		1	...	38	39
improving feature	1	…	…	26,35 18,19	…
	2	...	…	…	…
	...	...	…	…	…
	38	28,26 18,35	…	…	…
	39	…	…	…	…

3. The Theory of TRIZ Conflict Problem Solving Processes and Methods

In TRIZ, the resolution process to solve the contradiction problem is: First, analyze the problem, and transform the engineering problem into standard problem of TRIZ. Then, confirm the technical contradiction or physical contradiction according to the engineering parameters. The physical contradiction can be solved by the separation principle and the technical contradiction can be solved by the Technical Contradiction Matrix and the 40 common inventive principles (as shown in Fig. 1).

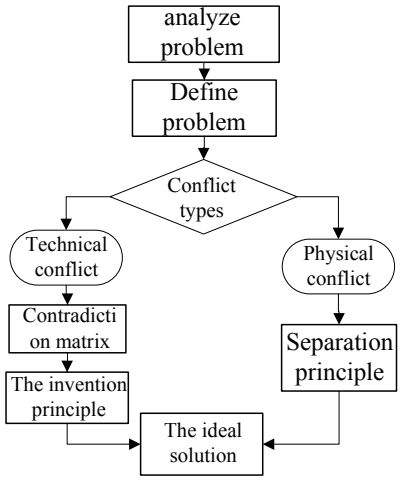

Fig. 1. The theory of TRIZ conflict problem solving processes.

The solving process is mainly the following several steps.

3.1. Analyze the Existing System

Problem analysis is one of the tools of TRIZ theory, which is an important step to solve the problems [9]. In the process of product design, when change some parts or subsystems in a design in order to improve the product performance, the properties of

some other components or subsystems are often affected, which leads to the whole system cannot achieve the desired results. In this case an in-depth analysis of a problem is necessary to find out what is the advantage and what is the disadvantage compared with the previous design.

3.2. Identify the Innovation Problem with the 39 Engineering Parameters

Identify the innovation problem is the process to transform the practical problem into standard TRIZ problem. In this process, general problem should be described with the 39 engineering parameters. In other words, identify the advantage as the improving parameter and the disadvantage as the worsening engineering parameter. And confirm that the problem is the technical contradiction or physical contradiction according to the specific engineering parameters.

3.3. Solve the Problem

According to the type of problem, if the problem is a physical contradiction, the separation principle can be used. If the problem is a technical contradiction, look up the worsening engineering parameter and the improving parameter in the Technical Contradiction Matrix to find out the corresponding inventive principle, which can inspire the designer to solve the contradiction problem and accomplish the innovation design.

4. Innovative Design of Automotive Steer-by-wire System Based on TRIZ Theory

4.1. Analyze the Problem

The current automotive steer by wire system's basic structure as shown in Fig. 2, It's working process is: When the steering wheel rotates, the torque sensor and the steering angle sensor are measuring the torque and the driver's steering wheel angle, then convert the data into electrical signals and input them to the ECU, according to the speed sensor and displacement sensor which is installed on the steering actuator the ECU can realize the control of the steering electromotor and the Steering motor output the required torque to drive the vehicle wheel steering, to realize the driver's intention to steering [10].

At the same time, The ECU through receiving the signal from wheel angle and wheel rotation sensor to Control the return-to-center motor which is under the steering wheel and let the motor produced the torque which is opposite the driver's steering operation, so as to realize the steering wheel return-to-center and simulate the corresponding road feel.

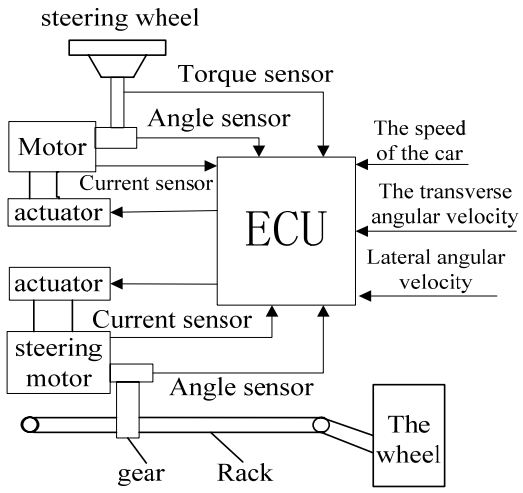

Fig. 2. The basic structure of automobile steering by wire system.

From the steering by wire system's structure and working process we can see that, Compared with the traditional mechanical steering system, the steering by wire system has reduced the number of the complex mechanical structure and the working process is more simple, it can provide more free space for the car's body design, and is advantageous for the interior structure of the layout.

Although the introduction of steer by wire system has brought many advantages, it has caused two problems:

Firstly, the driver's road feel reduced: due to the steering by wire system abandoned the mechanical connections between steering wheel and vehicle wheel, the driver's road feel be fully generated by simulating. Although there have developed many complex algorithm about how to simulation the road feel, the road feel of the steer by wire system is still not as good as the mechanical steering system.

Secondly, the automobile safety reduced: due to the steering by wire system abandoned the mechanical connections between steering wheel and vehicle wheel, the whole process should be to rely on the electronic components, Once in the steering process of electronic component failure, the car cannot complete steering action,, it will be in a state of completely out of control [11].

Through the analysis of the automobile steering process we can found, there is no problem for the driver to achieve the process of steering through the steering wheel, but for the feedback from the wheel to steering wheel there are some problems. So we focused on the innovative design of the feedback loop.

4.2. Define the Problem

According to the analysis of the above problem, transform the engineering problem into TRIZ standard questions, and find out the corresponding

engineering parameters. Due to the introduction of steer-by-wire system, the steering system can provide more freedom for the body, and the essence reason is that it reduced some complex mechanical structures, so the engineering parameter "The complexity of the device" has been improved. While the problems caused by the steer-by-wire system are the reduction of road feel and security. For the road feel, it can be described as an adaptive ability that a driver can perceive different road conditions and various situations of the car through the steering wheel. Here we use the engineering parameter "adaptability" to describe it is more fit. For Safety, It is clear that we can use the engineering parameter "safety" to describe it. To sum up, in the process of using steer-by-wire system to replace the traditional mechanical steering system, the improved engineering parameter is the "complexity of the device", and the worsening engineering parameter is "adaptive" and "safety". This is a rare situation of TRIZ technology conflict about one improvement of engineering parameter leading to the two different worsening engineering parameters.

4.3. Solve the Problem

By looking Conflict matrix up we can find the inventive principles recommended by TRIZ as shown in Table 2.

Table 2. Conflict matrix (part).

General engineering parameters		Worsening feature			
			32		37
			Adaptability		safety
Improving feature	45	The complexity Of the device	29,28,1,24,15 25,37		28,5, 24,10,19,13

Due to the improvement of the same engineering parameter of the problem has lead to the deterioration of two engineering parameters, in order to solve these two problems simultaneously, the ideal solution should see the problem as two pairs of conflicts, and use the inventive principles which is jointly recommended by the two pairs of conflicts to solve the problem, only in this way can we solve the two deteriorated parameters simultaneously. From the tab.2 we can see, the conflict matrix table recommended inventive principles are 29, 28, 1, 24, 15, 25, 37 and 28, 5, 24, 10, 19, 13. The Both recommended inventive principles are 28 and 24.

The 28th article invention principle: Alternative mechanical systems.

The 24th article invention principle: With the help of intermediary.

Through the above two principles we can easily think out that to resolve this problem we may use some kind of intermediary instead of mechanical system (The motor for return-to-center). Then combining the conflict matrix recommended another preferred inventive principle: The 29th article invention principle "Pneumatic and hydraulic structure". Naturally we think of the medium to solve the problem required should be pneumatic or hydraulic structure.

Through the analysis of vehicle active steering and steering wheel return-to-center, determine the final solution: by using the hydraulic structure of the intermediate to instead mechanical system. The hydraulic transmission can feedback road information and aligning torque to the steering wheel, so we can achieve the functions of road feel and return-to-center via using hydraulic transmission. Meanwhile it also improve the security of the system, the hydraulic transmission device can play a role in assisted steering when the ECU fails. So, both of the two problems have been solved.

5. Principle of Automotive By-wire Steering System Which Achieve Road Feel and Return-to-center Based on Hydraulic Equations

According to the solutions resulted by the previous theoretical analysis of the TRIZ, we can get the following schematic diagram (as shown in Fig. 3), it's the schematic diagram of automotive by-wire steering system which achieve road feel and return-to-center based on hydraulic.

The main work processes and functions of the system are as follows:

1) Process of steering: When the steering wheel is rotating, the torque sensor and the steering angle sensor are measuring the torque and the driver's steering wheel angle, then convert the data into electrical signals and input them to the ECU, the ECU keep on controlling the steering motor companioned with the signals from vehicle speed sensor and displacement sensor mounted on the steering linkage, then steering motor will output torque required for steering and drive wheel turning, thus achieving a driver's steering intent. In addition, this system designs the hardware and software of the controller fault-tolerant system in a redundant fault-tolerant ideology (as is shown in Fig. 4). While one set of the software (or steering motor) malfunctions, another set of software immediately enter the working state to ensure the security of the steering system.

2) Achieve road feel and return-to-center: In this wire steering system, the functions called road feel and return-to-center are formed as follows. Road force go through the front wheels steering force

sensing cylinder, via the servo valve, passed to road feel cylinder and return-to-center cylinder, at last it is transmitted to the hands of the driver.

3) Regulation: There is a servo valve installed in the hydraulic pipeline and it has two roles. The first is to adjust the servo valve and the intensity of road feel and return-to-center according to the motion state of the vehicle, so that it can provide the road feel full of comfortable and can truly reflect the characteristics of the tire and road adhesion. This allows the real-time adjustment of the intensity of road feel and return-to-center through the state of motion of the vehicle. The second is providing the flow rate keep pace with changes of wire steering system gear ratio.

4) Assisted steering while out of control: The hydraulic transmission device can play a role in assisted steering under the case of controller and sensor link failures because of the steering wheel and the steering rod are directly connected, this improve the security of the system.

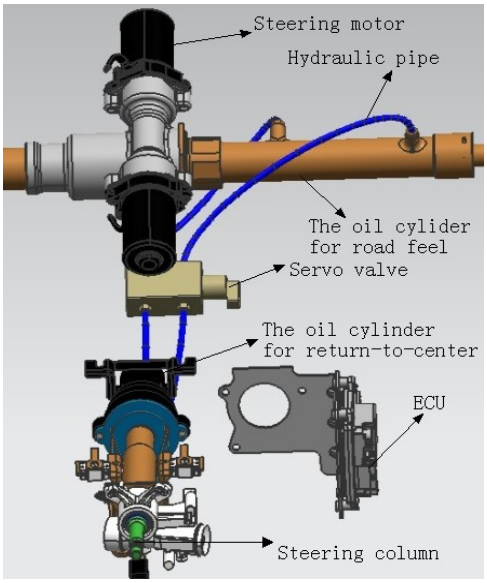

Fig. 4. Model of automotive by-wire steering system which achieves road feel and return-to-center based on hydraulic equations.

6. Conclusions

As the current SBW system exist's two big problems that have low road feel and security, this article uses the theory of TRIZ, for the situation of several engineering parameters simultaneously worsening, find the contradiction matrix corresponding inventive principles, Select the worsening parameters jointly recommended by the invention principle. Creatively put forward an automotive by-wire steering system which can achieve road feel and return-to-center based on hydraulic pressure. The system have not only solved the problem of how to achieve road feel and the return-to-center of the steering wheel, but also can Play an auxiliary steering role when the electric control system out of control, improve the security of the automobile wire control steering system.

Acknowledgements

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