Technical analysis of wheeled vehicle steering system

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Abstract. The steering system is an indispensable and important part of the wheeled vehicle, and its performance is directly related to the operational stability of the wheeled vehicle. This article introduces the working principle of the wheeled vehicle steering system. On this basis, it discusses the main components and functions of various types of steering systems. By analyzing the key technologies of the steering system, it provides a certain theoretical basis for the design of the steering system.

1. Working principle of wheeled vehicle steering system

The steering system refers to a set of mechanisms that can be operated by the driver to achieve steering wheel deflection and return. Its function is to change the driving direction of the vehicle according to the driver’s wishes and to keep the vehicle running in a straight line. In order to achieve this function [1], it is necessary to avoid the wheel sliding resistance relative to the ground during the steering process, and to ensure that the wheel performs pure rolling motion relative to the ground as much as possible. This requires each wheel of the automobile to perform circular motion according to its corresponding different radius [2]. See Figure 1 for details.

It can be seen from the figure that the rotation center O is on the extension line of the center line of the rear axle, and the left and right front wheels also need to make circular movement around the center point O. The relationship between the left and right front wheels deflection Angle is as follows:

\[ \text{ctg} \alpha = \text{ctg} \beta + \frac{B}{L} \]

Wheel turning radius refers to the distance between the rotation center O and the contact point between the outer steering wheel and the ground. In an ideal situation, the relationship between the \( R_{\text{min}} \) and \( R_{\text{max}} \) is:

\[ R_{\text{min}} = \frac{L}{\sin \alpha_{\text{max}}} \]
2. Wheeled vehicle steering system structure
The wheeled vehicle steering system has mainly gone through several stages of mechanical steering system, hydraulic power steering system, electronically controlled hydraulic power steering system, and electric power steering system. The intelligent and humanized development of the vehicle steering system has brought great convenience to the driver's flexibility in manipulating the automobile.

2.1. Mechanical steering system
Automobile mechanical steering system refers to a device that relies on the driver's physical strength as steering energy, instead of relying on external power [3]. Its main structure includes a steering wheel, steering shaft, cross joint, intermediate shaft, and steering gear, which is shown in Figure 2.

B -- Spacing between kingpins on both sides; L - wheel base; $\alpha$ -- Deflection Angle of external steering wheel; $\beta$ -- Deflection of internal steering wheel

Figure 1. Schematic of steering.
When the automobile is turning, the driver turns the steering wheel and transmits the torque to the steering gear through the steering shaft. After the deceleration and torque increase of the steering gear, the torque is transmitted to the steering knuckle arm through the steering rocker arm and the steering straight tie rod, so that the left-turn knuckle and its fixed left-turn wheel are rotated around the kingpin. At the same time, the left-turn joint and the left-turn wheel mounted on it will deflect the movement to the right steering joint through the left-turn trapezoidal arm, the steering bar and the right steering trapezoidal arm, so that the right steering joint and its fixed right steering wheel will generate the same deflection movement, so as to realize the steering function of the vehicle. As a mechanical steering system completely dependent on human power, the coordination of human and mechanical double movement plays a key role in ensuring the flexible and stable form of the vehicle in the process of driving.

2.2. Hydraulic power steering system
The hydraulic power steering system uses hydraulic pressure as the power. In actual operation, the steering action is still controlled by the driver, but the power energy acting on the steering mechanism is provided by the power device instead of relying entirely on human power, which reduces the labor intensity of the driver to a certain extent. The mechanism of hydraulic power steering system is shown in Figure 3.
Figure 3. Structure of hydraulic power steering system.

1 -- Steering wheel; 2 -- Steering shaft; 3 -- Steering control valve; 4 -- Steering screw; 5 -- Rack piston; 6 -- toothed; 7 -- rocker arm; 8 -- Steering main lever; 9 -- Steering knuckle; 10 -- Steering tie bar; 11 -- Steering trapezoidal arm; 12 -- Steering oil cup; 13 -- Steering hydraulic pump; L -- Turn left to the power room; R -- Right steering power room;

The steering hydraulic pump is installed on the automobile engine, and the crankshaft is driven by the belt to output oil pressure. The steering oil cup has inlet and outlet tubing connectors, which are connected with the steering hydraulic pump and steering control valve respectively through the tubing. By pressurizing the oil with hydraulic pump, the power generated by hydraulic pump can be used to push the mechanical steering gear to work, so as to achieve the purpose of steering control.

2.3. Electro-hydraulic power steering system

The electro-hydraulic power steering system adds sensors and steering control units on the basis of the hydraulic power steering system. The use of sensors introduces vehicle speed to the steering system. The use of the steering control unit enables the electro-hydraulic power steering system to control the motor according to different driving conditions. Thereby controlling the output of the electric hydraulic pump to achieve the purpose of controlling the operation of the entire steering system. The main structure of the electro-hydraulic power steering system is shown in Figure 4.
The electro-hydraulic power steering system mainly includes electric motor, controller, rotation angle sensor, gear pump, oil storage tank, and steering gear, etc. Among, the oil storage tank, gear pump, motor, and steering control unit are integrated, exchanging necessary information and data with the vehicle's central control unit through the CAN. The structure of the steering gear is the same as that of the hydraulic power steering gear. The gear pump provides hydraulic power for the electro-hydraulic power steering system. The gear pump is driven by a small inertia, internal rotor, three-phase brushless DC motor, and the power supply comes from the 12V battery of the automobile. Compared with the hydraulic power steering system, the electro-hydraulic power steering system has a better steering feel and lower energy consumption.

2.4. Electric power steering system

The electric power steering system mainly includes steering input shaft, steering sensor signals, control unit, battery connection, speed signal line connection, intermediate shaft, gear, motor, electromagnetic clutch control signal, and motor control signal.

Figure 4. Structure diagram of electro-hydraulic power steering system.

Figure 5. Structure diagram of electric power steering system.
The electric power steering system is an intelligent steering system, usually composed of torque sensors, speed sensors, electronic controllers, motors and other mechanisms. The structure of the electric power steering system is shown in Figure 5.

After the vehicle is started, the system officially begins to work. When the vehicle speed is lower than a certain speed, the system will feedback the vehicle speed signal to the control module. The control module sends a control signal to the servo motor by receiving data of steering wheel torque value, driving direction, and vehicle driving speed, the servo motor will output the corresponding torque according to the received command to generate auxiliary power. When the vehicle travels straight and does not turn, the control unit will not send a torque signal to the servo motor, the current of the servo motor is close to zero. So when driving straight without turning, no power is consumed. When the vehicle speed is higher than a certain speed, the current of the servo motor is also close to zero, so the boost is reduced as the vehicle speed increases. Based on the above, no matter whether the vehicle is in a high-speed or low-speed state, the automobile has good stability.

### 3. Key technology of automobile steering system

The hydraulic power steering system, electro-hydraulic power steering system, and electric power steering system achieve turning by adding different types of power energy to the original basis of the mechanical steering system. Therefore, no matter what kind of steering system the vehicle uses, its basic mechanical structure can still be attributed to the mechanical steering system. The key points that need to be paid attention to in the design process of the steering system are analyzed below through three aspects.

#### 3.1. Steering system transmission ratio determination

The purpose of steering system transmission ratio determination is to increase the output torque of the steering gear and reduce the input torque of the driver. The appropriate transmission ratio will also enable the entire steering system to reasonably use limited space resources to meet the needs of the overall vehicle layout and vehicle steering performance.

Establish the relationship between the steering wheel force \( F_h \) (N) and the steering wheel diameter, steering gear angle transmission ratio, steering vertical arm length, and knuckle arm length, see Equation 2.

\[
F_h = \frac{2M_R * I_1}{i_w D_{sw} I_2}
\]

Among, \( D_{sw} \) - steering wheel diameter; \( I_w \) - Angle transmission ratio of steering gear; \( I_1 \) -- Length of steering vertical arm; \( I_2 \) - Length of steering knuckle; MR- in-situ steering moment;

In the actual design process, the ratio of \( I_1 \) to \( I_2 \) can be approximately 1, taking into account the spatial arrangement and other factors. According to Equation 2, on the basis of the target value of steering force and steering torque, only the diameter of steering wheel and angle transmission ratio of steering gear need to be considered.

#### 3.2. Steering system configuration

When the body structure is known, the structural arrangement of the steering system is regarded as the determination of the spatial position of the steering gear. The determination of the spatial position of the steering gear directly affects the angle between the steering vertical arm and the straight rod and the angle between the steering straight rod and the steering knuckle arm, which in turn affects the amount of force applied by the driver on the steering wheel. The design of the angle of the steering straight rod is very important.
3.3. Steering trapezoidal structure design
The steering trapezoidal structure form mainly has the integral type and the break type, when the automobile front suspension is not independent suspension, should use the integral steering trapezoid structure, when the front suspension is independent suspension erection timing, generally adopts the break type steering trapezoid structure.

For the integral steering trapezoid, the straight pull rod can be placed in front and the data can be imported into Minitab for analysis, then can get CPK=3.00, the process capability is upgraded from D-level to A++-level, and the management cost of QCOS could be optimized later, reducing the frequency of random inspections and saving management costs.

4. Conclusions
At present, various vehicle factories are using SPC to carry out torque process control capability analysis, but SPC is only an analysis tool.

Only by combining 5W, fishbone diagram and other problem solving tools to carry out problem solving on specific torque points, can the torque process control ability be effectively improved, and a closed-loop solution to the problem can be formed.

References
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