Proceedings of the 3rd International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/125/2025.21392

Vehicle Motion Sensors and Their Applications

Chi Xu[1,a,*]
[1]*Central South University, No.932 South Lushan Road, Changsha Hunan, 410083, P.R. China*
a. 8203220710@csu.edu.cn
**corresponding author*

Abstract: Vehicle motion sensors are indispensable components in contemporary automotive systems, offering real-time insights into the vehicle's dynamic state. This paper presents a comprehensive overview of vehicle motion sensors, which serve as vital components in the sophisticated automotive systems of today. It delves into the operational principles of various types of motion sensors, encompassing speed sensors such as magnetoelectric, Hall effect, and photoelectric sensors, as well as acceleration sensors like piezoresistive, piezoelectric, capacitive, and MEMS sensors. These sensors find extensive applications in engine control, wheel speed regulation, brake systems, and angular speed management. By monitoring crucial motion parameters including speed, acceleration, and angular velocity in real-time, these sensors furnish indispensable data that is essential for a range of automotive control systems, such as anti-lock braking systems, electronic stability programs, and autonomous driving technologies. By elucidating these sensors, the automotive industry can harness their potential to elevate vehicle performance, safety, and operational efficiency.

Keywords: vehicle motion sensors, speed sensors, acceleration sensors,automotive electronics

1. Introduction

With the improvement of the degree of automobile electronization and the continuous development of automobile electronic technology, the intelligent and safety requirements of vehicles are getting higher and higher, and various electronic control systems with high integration degree are used in the parts of automobile engine, chassis and body. Vehicle motion-related sensors monitor key motion parameters such as speed, acceleration, and angular velocity in real time, furnishing indispensable data for a myriad of automotive control systems such as anti-lock braking (ABS), electronic stability program (ESP), and autonomous driving. The objective of this paper is to provide a comprehensive overview of the working principle of vehicle motion sensors and their multifaceted applications.

2. Working Principle of Vehicle Motion Sensors

Vehicle motion sensors can be categorized into several groups based on their measurement parameters, encompassing speed sensors, acceleration sensors, angular velocity sensors, among others.

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2.1. Speed Sensors

Speed sensors are instrumental in measuring the vehicle's speed, which is paramount for engine control, brake systems, and speed regulation. The following are common types of velocity sensors:

2.1.1. Magnetoelectric Speed Sensor

This sensor leverages the principle of electromagnetic induction. As a toothed wheel rotates past a magnetic core and coil, it generates an alternating current signal. The amplitude of this signal is directly proportional to the speed of the toothed wheel.

The structure of the electromagnetic induction speed sensor is mainly composed of permanent magnets and coils, which are installed on the housing near the output shaft of the automatic transmission.

When the output shaft rotates, the induction rotor on the output shaft also rotates, and as the teeth on the rotor periodically move closer to and away from the electromagnetic induction coil, the magnetic induction intensity of the magnetic field passing through the coil also changes, and then the induction current in the coil changes periodically. The higher the speed of the output shaft, the higher the frequency of the induced voltage, based on this principle, the ECU can calculate the speed by measuring the frequency of the induced voltage[1].

2.1.2. Hall Effect Sensor

There is another type of electromagnetic sensor known as a Hall effect sensor.Utilizing the Hall effect, this sensor detects the passage of magnetic poles, resulting in a digital output signal indicative of speed.

The Hall effect sensor detects changes in the magnetic field generated by a permanent magnet and a rotating soft iron rotor. These changes induce a voltage in the sensor, which is processed to produce a digital output signal indicative of speed. Nowadays, there are some current sensors based on Hall effect are widely used in vehicle motion detection because of their compact size, low power consumption, good economy, and high dynamic range[2].

The structure of the Hall sensor is similar to that of the electromagnetic wheel speed sensor, which is composed of two main parts: sensing head and tooth ring. The sensor head is composed of permanent magnet, Hall element and electronic circuit.

When the tooth gap of the gear ring is facing the sensor head, the magnetic field line passing through the Hall element is the most dispersed, that is, the magnetic field where the Hall element is located is weak. In contrast, when the tooth tip of the gear ring is facing the sensing head, the magnetic field line passing through the Hall element is the most concentrated, that is, the magnetic field where the Hall element is located is strong.

With the continuous rotation of the tooth ring, the number of magnetic field lines passing through the Hall element is constantly changing in a continuous period. According to the rotating property of the gear ring, the periodic change of the magnetic field of the Hall element will make it output sinusoidal voltage signal.

2.1.3. Photoelectric Speed Sensor

This sensor employs a light-emitting diode and phototransistor to detect the passage of slots or holes on a rotating disk. This detection triggers the generation of a digital output signal.

The photoelectric speed sensor is composed of a light shield and an LED. The light-emitting diode emits light through slots or holes on the rotating disk, which is detected by the phototransistor. When the light shield does not block the light of the LED, the light of the LED is irradiated to the

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photosensitive triode, and the collector of the photosensitive triode has a current flow at this time, the tube is switched on; On the contrary, the tube is closed when the light is blocked. Thus, the frequency of the output pulse signal generated depends on the speed of the drive shaft, that is, on the speed of the vehicle. The resulting electrical signal is processed to generate a digital output proportional to the speed.

2.2. Acceleration Sensors

Acceleration sensors gauge the vehicle's acceleration, which is critical for collision detection, airbag deployment, and suspension control. Common types include:

2.2.1. Piezoresistive Acceleration Sensor

This sensor converts acceleration into an electrical charge through the piezoresistive effect. The generated charge is proportional to the acceleration.

When the sensor is subjected to acceleration, the mass block will generate inertial force, which is applied to the cantilever beam. The cantilever beam deforms under the bending moment of the inertial force, resulting in bending stress, which causes the resistance value of the diffusion resistance to change, and the voltage output is generated proportional to the acceleration through the Wheatstone bridge composed of four resistor.

2.2.2. Piezoelectric Acceleration Sensor

This sensor converts acceleration into an electrical charge through the piezoelectric effect. The generated charge is proportional to the acceleration experienced by the sensor.Acceleration deforms the sensor, causing a change in the polarization of the piezoelectric material. This change produces an electrical charge that is directly proportional to the acceleration.

The key components of piezoelectric acceleration sensor are the piezoelectric element made of quartz or ceramics, the mass block, the spring system that connects the mass block to the sensor's housing, the electrodes and the signal conditioning circuit.

When the sensor experiences acceleration, the mass block tends to remain stationary due to inertia, causing it to exert a force on the piezoelectric element.This force deforms the piezoelectric element, generating a proportional electrical charge on its surfaces.The electrodes collect this charge and convert it into a voltage signal, which is then amplified and processed by the signal conditioning circuit.The magnitude of the voltage signal is directly related to the acceleration experienced by the sensor[3].

2.2.3. Capacitive Acceleration Sensor

This sensor utilizes changes in capacitance to measure acceleration. The relative movement of two parallel plates, separated by a small gap, alters the capacitance, which is then converted into an electrical signal proportional to the acceleration.

The structure of the capacitive acceleration sensor comprises two fixed plates and a movable plate (mass block), and a capacitor is formed between the movable plate and the fixed plate. There is a linear relationship between capacitance change and external acceleration signal, and the magnitude of external acceleration can be obtained by detecting capacitance change. The relative movement of the parallel plates alters the capacitance between them. This change is converted into an electrical signal proportional to the acceleration.

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2.2.4. MEMS Acceleration Sensor

A significant percentage of the acceleration sensors employed in modern automobiles are Micro Electro Mechanical Systems (MEMS) acceleration sensors. These sensors are rooted in MEMS technology, which integrates mechanical structures and electronic circuits onto a minuscule chip. Both the aforementioned piezoresistive and capacitive acceleration sensors utilize MEMS technology, and there are also other forms, such as resonant MEMS acceleration sensors and inertial measurement unit[4].

MEMS acceleration sensors are based on MEMS technology, which integrates the mechanical structure and electronic circuits on a tiny chip. The micro-machined mass moves under acceleration, altering the capacitance or resistance of the sensor. This change is converted into an electrical signal proportional to the acceleration.

The application of MEMS is not limited to acceleration detection, it is also used in speed detection[5].Nowadays, the ability of information collection and algorithm integration between various sensors is constantly improving, and MEMS sensors are also widely used in the dynamic measurement of vehicles[6].

3. Applications of Vehicle Motion Sensors

Based on the principle of speed sensor and acceleration sensor, many other vehicle motion sensors have appeared, such as speed sensor, wheel speed sensor, angular speed sensor and so on. Many vehicle motion control systems can be realized through the application of mutual cooperation between various sensors

3.1. Engine Control

The engine speed sensor is a very important sensor in the engine centralized control system. Its function is to detect the engine speed and input the test results to the vehicle instrument system to display the engine working condition. Or input the Engine Control Unit (ECU) of the engine control system and some control systems of the chassis for the control of fuel injection amount, ignition advance Angle, power transmission, etc.

The detection of engine speed is usually achieved by the detection signal of the crankshaft position sensor. In a car, the speed is often calculated based on the measured engine speed and wheel speed. For the speed read by the steel wire flexible shaft tachometer, only the driver shows the rotation speed of a shaft, in order to know the speed data of various devices, but also the information obtained by the engine tachometer, applied to the speedometer, brake anti-lock device, engine control, fuel calculation, etc., so the speed signal must be converted into an electrical signal to be read by a computer.

3.2. Wheel Speed Control

Various electronic control systems related to automotive braking or drive such as anti-lock braking, drive anti-slip (ASR) or electronic brake force distribution (EBD), steering brake control (CBC), electronic stability program (ESP) and other system controls need to obtain wheel speed conditions. At the same time, the speed is usually measured by the rotation of the car's transmission system, which is converted to the speed of the car's driving wheels. At present, wheel speed sensor has been more and more widely used in ABS, gradually replacing the traditional speed sensor, body speed sensor and so on[5].

The wheel speed sensor generally detects the speed of the wheel directly, and the speed of all wheels is detected, and the detection result is input to the ECU of the braking or drive control system such as ABS/ASR. Wheel speed sensors are generally mounted on the drive wheel, driven wheel, main reducer or transmission output shaft.

3.3. Brake Systems

The function of the speed sensor is to detect the speed of the vehicle, and input the detection result to the vehicle instrument system for displaying the speed; Or used in automatic transmission system, cruise control system, etc. It is used to measure the speed of the car, so that the engine control, automatic start, ABS, traction control system (TRC), active suspension, navigation system and other devices can work normally

In anti-lock braking systems (ABS), speed sensors measure the speed of each wheel. This data enables the system to regulate brake pressure, preventing wheel lock-up and enhancing braking performance.

3.4. Angular Speed Control

Angular speed sensors are used in electronic stability control systems to detect and correct vehicle yaw, in lane departure warning systems to alert drivers when they drift out of their lane, and in other advanced driver assistance systems.

The working principle of the angular velocity sensor is mainly based on the principle of Coriolis Force and the principle of conservation of angular momentum[7].The main purpose of the angular speed sensor is to detect the rotational angular speed of the car body when it turns, which plays an important role in the detection of the motion state of the vehicle.

In emerging automotive technologies such as Vehicle Stability Control (VSC), Vehicle Stability Assist (VSC), Areas such as VSA and Active Stability Control (ASC) are essential.

4. Conclusion

Vehicle motion sensors are fundamental components in modern automotive systems, providing real-time data on the vehicle's dynamic state. This paper has elucidated the working principle of various motion sensors commonly used in vehicles, including their classification, operational mechanisms, and significant applications. By gaining a deeper understanding of these sensors, the automotive industry can innovate to further enhance vehicle performance, safety, and operational efficiency.

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