ABSTRACT: Direct tire pressure monitoring system (d-TPMS) is easy to be disturbed, and its battery life is not long while the indirect TPMS can’t distinguish the condition that four wheels are low pressure at the same time and there is no way to provide detailed values of the tire pressure for indirect TPMS. This paper proposes a hybrid TPMS to solve these problems. Based on the perfect database of the indirect TPMS, all wheels’ detailed pressure can be got by dealing with the data which only comes from a sensor in one wheel. This method combines the advantages of the two sides, which has the advantages of simple structure, low cost, stable and lasting work. Through the real vehicle road test, the effect is good. The development of hybrid TPMS will have a positive effect on the application of TPMS in China.
After the vehicle starts, the original indirect TPMS starts to read the wheel speed signal through ABS, then the host access and calculate the data which makes vehicle tire pressure under monitoring. The data will be sent to the host storage unit if the tire pressure is normal which is ready for the next data comparison; the host will awake the tire pressure through the LF transmitter when the tire pressure is abnormal, then the sensor starts to work. The measurement data got from sensor will be transmitted through the RF circuit to host (Wang & Chen 2014). After the host received the data from the pressure sensor and the wheel speed sensor, each wheel’s tire pressure could be calculated and sent to the display device, when the tire pressure exceeds the safety value, the alarm system works to ensure the safety of the vehicle. In the system, in order to ensure the reliability of data transmission, the transmission distance is shorten by installing the tire pressure sensor in the left front wheel of vehicle.

3 ALGORITHM IMPLEMENTATION OF H-TPMS

3.1 Wheel speed signal acquisition of the four wheels

ABS system has become a standard safety device for vehicle. Wheel speed sensor as the key module in the system, ABS system through it to get the wheels of wheel speed, whose essence is reading sensor signal of pulse number and processing operations to get wheel speed.

The wheel speed signal is obtained by the ABS system's wheel speed sensor. It is shown in Figure 2, where the A1 represents the signal of the wheel speed, A3 represents the pulse got during the time A2. Combined with the tire pressure test data, the way to handle the wheel speed signal is recording the 4 wheels’ pulse number sent out by the wheel speed sensors per distance. The pulse number is recorded per period of time and it is used for the next calculation. The data in each group as follows: \( N_1, N_2, N_3, N_4 \).

3.2 The establishment of MAP

The relationship between the No.1 wheel's tire pressure, its pulse number and the vehicle's speed can be established after the experiment, which helps computer get the MAP as shown as Figure 3. The polynomial fitting based on the MAP.

\[
P_1 = P_0 + K_p \cdot N_1 + K_p' \cdot N_1^2 + K_v \cdot V_1 + K_v' \cdot V_1^2 + K_{pv} \cdot N_1 \cdot V_1 + \cdots
\]  \hspace{1cm} (1)

where \( P_1 \) = the pressure of no.1 wheel which has the pressure sensor inside; \( V_1 \) = vehicle’s speed; and \( P_0, K_p, K_p', K_v, K_v', K_{pv} = \) the fitting coefficient.

3.3 The determination of the wheel ratio coefficient between the number of pulses

Experiments were carried out in the four round of pressure were normal. In the No. j speed test, the proportional coefficient \( k_j \) is got by making No. j divided by No.1 wheel.

During the First speed test, according to test requirements, record the number of pulses per wheel, and compare them with the wheel No. 1.

\[
k_j = \frac{N_j}{N_1}
\]  \hspace{1cm} (2)

Do the test at different speeds, get the Matrix about \( K_j \).

The coefficient matrix \( \{k\} \) of each line fitted to the speed function, and the relationship between \( k_1, k_2, k_3, k_4 \) and the speed is:

\[
\{k\} = \begin{bmatrix}
k_1 \\
k_2 \\
k_3 \\
k_4 
\end{bmatrix} = \begin{bmatrix}
a_{02} + a_{12} \cdot V_a \\
a_{03} + a_{13} \cdot V_a \\
a_{04} + a_{14} \cdot V_a \\
1
\end{bmatrix}
\]  \hspace{1cm} (3)

The resulting data \( \{k\} \), \( \{k\} \) will be stored in the TPMS memory.

Then, the mathematical relationship between the pulse number of each wheel and the No.1 wheel is:

\[
N_j = k_j \cdot N_1
\]  \hspace{1cm} (4)
3.4 Calculate the air pressure of each wheel

During the vehicle driving, the wheel’s pulse number correspond to the No.1 wheel could be calculated by combining \( \{k\} \) with the wheels’ pulse number which is sent from the wheel speed sensor:

\[
N_{1,j} = \frac{N_j}{k_j}
\]

where \( N_{1,j} \) = the number of pulse number of the No.j wheel corresponds to the No.1 wheel.

Based on \( v_{ij} \) and \( N_{1,j} \), and put them into the formula (1). \( P_2, P_3, P_4 \) which represent the pressure, can be calculated from the polynomial. The detailed methods have been proposed in the patent (Yanshan University 2013).

4 HARDWARE IMPLEMENTATION OF H-TPMS

4.1 Part design of tire pressure sensor

Tire pressure sensor is Infineon sp37 type pressure sensor, due to sensor is mounted to an inner tire. Therefore, it is necessary of independent battery power supply (Xiao 2011). The hardware circuit of SP37 as shown in Figure 4, it has filter circuit, the external crystal vibration circuit and the antenna matching circuit.

Data from the pressure sensor is transmitted to the host by RF high-frequency communication. The antenna design need to consider two aspects: one is tire wire of the module of electromagnetic interference; the second antenna is as small as possible and impedance matching (Huang 2013). The valve nozzle is often used as an antenna, which is convenient for integrated design.

![Figure 4. Schematic of SP37 circuit diagram connection.](image)

4.2 The wheel speed signal process circuit design

Wheel speed sensor has electromagnetic induction type and Hall Effect and eddy current type in ABS in present. The first and second type are often used. The output signal of Electromagnetic induction type is sine wave. The output of Hall Effect type is rectangular wave that amplitude is little. In the process of the number of pulse acquisition. Firstly, wheel speed signal should be processed. Make it into a 50% duty cycle of square wave signal (Jiang 2014). The signal processing circuit is mainly composed of operational amplifier LM358, comparator LM339 and resistance and capacitance, etc. Using the signal processing circuit is shown in Figure 5.

![Figure 5. The circuit for processing wheel speed signal.](image)

5 DESIGN OF THE SYSTEM PROGRAM.

When h-TPMS works, the tire pressure sensor of the first wheel always sleep to reduce the energy consumption of the tire pressure sensor, prolong the working life. Indirect part is responsible for the real-time monitoring in the beginning. When identifying abnormal wheel speed, the sensor will be activated. Use LF external awakening signal as activation patterns. After activating the sensor, transmit data to host by RF. The data frame format of RF is shown in the Table 1.

| Setting            | Word Length |
|--------------------|-------------|
| Data head          | 8bits       |
| Sensor ID          | 32bits      |
| pressure           | 16bits      |
| The X axis acceleration | 16bits   |
| The Z axis acceleration | 16bits   |
| temperature        | 16bits      |
| voltage            | 16bits      |
| CRC verify         | 8bits       |

The sensor can be activated only when the tire pressure ID confirm. It will reduce the energy consumption of sensor. The working process is shown in Figure 7.
When the condition is abnormal, the wheel pressure sensor will be activated by LF wake signal. Its data frame format is shown in Table 2.

Table 2. LF wake signal data frames.

| FH   | Sensor ID | check code |
|------|-----------|------------|
| 8bits | 16bits    | 8bits      |

After Manchester decoding the original data, through the identification of tire ID code, tire pressure module can be waked up to measure the tire pressure data.

6 CONCLUSION

Test results show that tire pressure that h-TPMS monitors match with actual tire pressure and it can show the pressure values. So it can solve the problem of identify abnormal tire pressure when four wheels are under pressure or over pressure at the same time. Based on the development of indirect TPMS monitoring system has already connected with CAN bus, it makes h-TPMS monitoring system and the integration of vehicle electronic control is easy to implement. The system accumulated a large number of experimental data based on the process of the indirect TPMS. So it reduce more cost of tire pressure monitoring.

With the improvement of the safety of the car, TPMS will become an important safety device. H-TPMS makes TPMS easier to have, which has a profound impact on the popularity of the tire pressure monitoring system in China.

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