DIFFUSION DEFLATION DETECTION USING WHEEL SPEED SIGNALS

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Paper Number 05-0082

ABSTRACT

For increased safety and economic reasons in the world, motor vehicle manufacturers are beginning to install TPMS (Tire Pressure Monitoring System).
There are two types of TPMS in the market; one is a direct TPMS using pressure sensor, the other is an indirect TPMS using the wheel speed sensor signals from ABS.
Most indirect TPMS are unable to detect a 4-tire simultaneous deflation condition because indirect TPMS are based on the principle that the 4-tire speed signals are compared with each other.
However, the SRI Group (Sumitomo Rubber Industries, Ltd.) has developed an indirect TPMS which can detect a 4-tire simultaneous deflation based on a newly developed principle using wheel speed signals from the ABS.

INTRODUCTION

Recently, Tire Pressure Monitoring Systems are being widely introduced in the car industry because of the safety and economic reasons. In Europe, 'the No Spare Tire Concept' is promoted by the car manufacturers and runflat tires are introduced in the cars to realize this concept. Here, TPMS is inevitably required to avoid the tire burst caused by long time driving in a deflated condition. In the USA, the T.R.E.A.D Act was signed in 2000 and required all new cars to be equipped with an appropriate TPMS.
Now, there are two basic types of TPMS in the world. One is the so called 'Direct TPMS' and the other is the 'Indirect TPMS'.
A Direct TPMS detects tire deflation using a pressure sensor and transmits the data to the receiver. Therefore, this system is accurate and able to detect deflation in any combination of 4-tires. But, on the contrary, this system is expensive, less durable and more difficult to maintain.
Most indirect TPMS detect tire deflation by comparing wheel speeds from the ABS sensor with each other. Therefore, this system is less accurate than a direct TPMS and can basically detect deflation in just one tire. But, on the contrary, this system is inexpensive and maintenance free.

PRINCIPLES OF THE CURRENT INDIRECT TPMS

Figure 1. shows the principle of the current indirect TPMS. The rolling radius of the tire becomes smaller in proportion to the rate of deflation and therefore the wheel speed of the deflated tire increases. Most indirect TPMS give a warning by comparing wheel speed signals from the ABS. Here, the sensitivity of rolling radius change caused by the deflation is higher in the case of low aspect ratio tires (including runflat tires) than that in the case of high aspect ratio tires such as 82% series. Therefore, such an indirect TPMS can detect deflation of runflat tires and modern generation low profile tires.
However, the tire rolling radius comes under the influence of production tolerances, cornering radius, weight distribution on cornering, acceleration

condition, braking condition, rough road, low myu roads, etc. Therefore, we introduced various corrections and rejections in our system to improve accuracy.

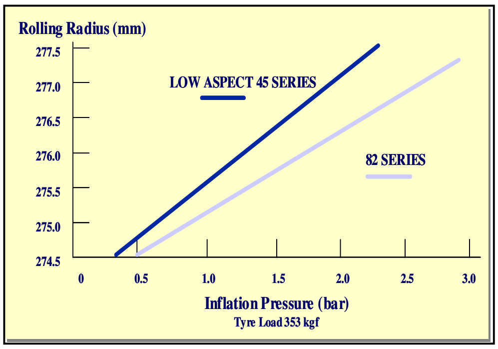
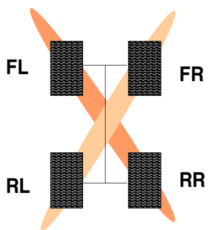


Figure 1. Tire rolling radius change according to the inflation pressure.

We introduced the diagonal difference defined by the following equation and detect tire deflation by referring to this value. This equation may cancel out the difference in 4-wheel speeds when cornering.

$$DEL = \frac{2 \times \{(FL + RR) - (FR + RL)\}}{FL + FR + RL + RR} \times 100$$

FL : Speed of Front Left tire
FR : Speed of Front Right tire
RL : Speed of Rear Left tire
RR : Speed of Rear Right tire



FEATURES OF CURRENT INDIRECT TPMS

Finally, current indirect TPMS has the following features.

-- No additional sensors.
-- Can detect deflation in one tire.
-- Is applicable for the low aspect tires including runflat tires.
-- Can work on the various types of cars, such as, front-driven car, rear-driven car, 4-wheel driven car and a limited slip differential equipped car.

APPROACH FOR DIFFUSION DEFLATION DETECTION

All tires lose air naturally over time and we refer to this condition as '4-Tire Diffusion Deflation'. To detect diffusion, we introduced a new concept. That is, ' Load sensitivity of rolling radius ', which means a tire rolling radius change rate in % when the tire load shifts. Figure 2 shows a tire rolling radius change rate in % when the tire load shifts 250kg. We found that the tire rolling radius change rate in the deflated condition (140 kPa) is smaller than that in the normally inflated condition (200kPa) over a wide aspect ratio range of tires (70% to 50%).

<Test condition> (INDOOR TEST)

Tire size : 185/70R14 Delta Load=250 kg
: 205/60R15
: 225/50R17

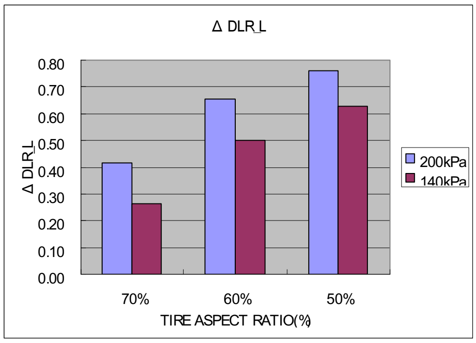


Figure 2. Load sensitivity of tire rolling radius.

TEST RESULTS

Considering that the load shift occurs under cornering and acceleration/deceleration, we can detect a 4-tire diffusion deflation by comparing the tire rolling radius change rate under cornering or acceleration/deceleration between a normally inflated tire and a deflated tire.

Figure 3 shows the rolling radius change in the normally inflated condition under cornering and

Figure 4 shows that of a 4-tire 40% deflated condition. Here, the slope of line represents the load sensitivity of the tire in each condition. There is a difference in slope and thus we can detect a 4-tire simultaneous deflation.

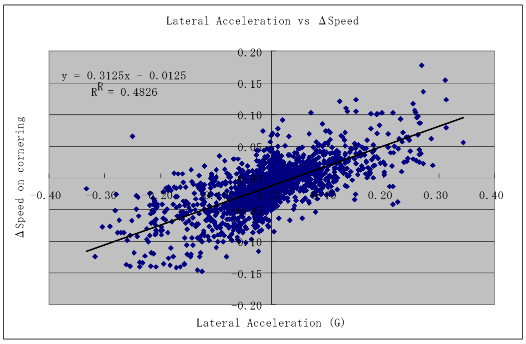


Figure 3. Speed difference in cornering due to load shift. (Normally inflated condition)

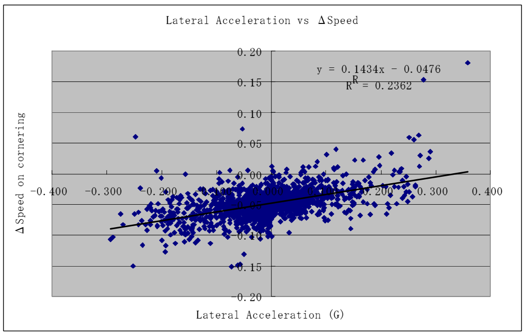


Figure 4. Speed difference in cornering due to load shift. (4-tire 50% deflation condition)

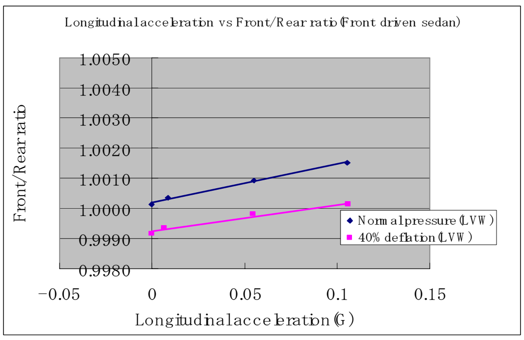


Figure 5. Rolling radius change rate under acceleration (Front driven sedan)

The load sensitivity during acceleration and deceleration was also evaluated using a front driven car and a rear driven car.

Figure 5 shows the rolling radius change of a normally inflated and a 4-tire 40%-deflated condition under acceleration using a front driven sedan.

Figure 6 also shows the rolling radius change of a normally inflated and a 4-tire 40%-deflated condition under acceleration using a rear driven sedan.

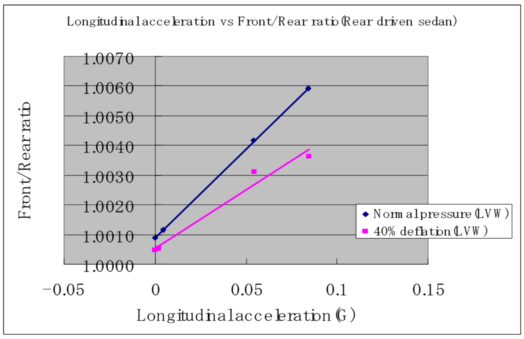


Figure 6. Rolling radius change rate under acceleration (Rear driven sedan)

In the both figures, there is difference of slope between normally inflated tire and 40% deflated tire. And in addition, we can easily find that the intercept of the line decreases when all 4-tires are deflated because the difference of tire rolling radius between the front axle and the rear axle varies according to the inflation pressure. Therefore, we can detect a 4-tire diffusion deflation condition by comparing the slope or intercept of the line.

TEST RESULT ON THE PROVING GROUND

To determine if this concept can meet the requirements of the NPRM by NHTSA, we made additional testing as follows. We used the High Speed Test Track at the Transportation Research Center, Ohio as the test surface. And the test vehicle was the front driven sedan. We designed the driving pattern to include acceleration, deceleration, braking and stop and driving in the speed range 50km/h to 100km/h to simulate the real world.

We did a calibration, of course, at the normal pressure condition under this driving pattern and then checked to see if the system could finish calibration within 20 minutes and detect a 25% 4-wheel diffusion deflation. within 10 minutes.

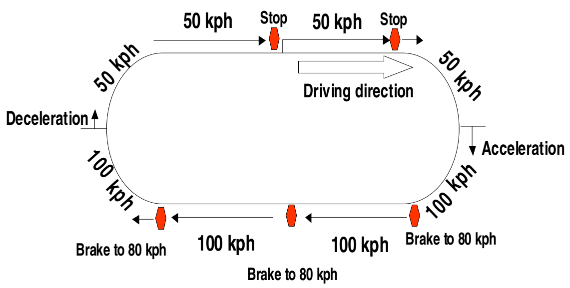


Figure 7. Driving pattern

Table 1. shows that this system could complete the calibration 17 minutes and detect a 4-tire 25% deflation in 6 minutes under the two different load conditions.

Table 1.

Test results on the proving ground

	Weight condition	Results
Calibration time (min.)	3 persons	17
Detection time (min.)	3 persons	6
@ 25% (4-Tire)	GVW	6

CONCLUSIONS

We have developed a 4-tire simultaneous deflation detection indirect TPMS. This TPMS system only requires the wheel speed sensor signals from the vehicle ABS.

On the proving ground, this system showed that the time to reach full system capability following reset is within 20 minutes and the detection time is within 10 minutes.

We also believe that this indirect TPMS system will meet new NHTSA requirements and be able to contribute to a driver's safety while maintaining superiority in cost and durability.