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Development and Verification of a Tire Three-component Force Sensor for Increasing the Control Performance of the Chassis Electronic Control System

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Abstract: *This paper presents a tire three-component force sensor which can be used to increase electronic control system performance. Firstly, the shape and strain gauges distribution scheme of the tire three-force sensor are designed. As a car-installed force sensor, it is in small size, and there is no crosstalk between forces according to simulation result. Secondly, the force sensor entity is calibrated by using self-developed calibration device. Finally, experiments on vehicle is carried out. This paper is an important guidance for the design of a car-installed tire three-component force sensor. By supplying real-time tire forces to electronic control system, it offers a new way of developing intelligent tire.*

Keywords: *tire three-component force sensor, calibration, electronic control system, intelligent tire*

1. Introduction

Tires are the only part of the vehicle that contacts with the road surface, and their mechanical properties are closely related to the vehicle performance. [1] When getting the real-time forces of tires, the performance of electronic control systems such as ABS and ESP can be increased. For example, friction coefficient between road and every tire can be deduced from tire forces, thus the braking forces optimum allocation of tires can be realized, which increases vehicle's active safety. [2]

There are many kinds of tire force sensors used for tire mechanical properties test. Such as wheel load measurement system of Michigan Scientific Corporation (as is shown in Figure 1) and multi-component measuring hub of Kistler Instrumente AG (as is shown in Figure 2). [3~4]

Figure 1: Wheel load measurement system of Michigan Scientific Corporation

Figure 2: Multi-component measuring hub of Kistler Instrumente AG

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As widely used commercial products, they are mainly used to get tire mechanical properties of a trial vehicle. The results provide reference for the development of tires and vehicles. When installed on the vehicle, special rim is needed, which limits their application.

In this paper, a small size tire three-component force sensor is developed, which makes it possible to get real-time tire forces of all vehicles, not only trial vehicles.

The remainder of this paper is organized as follows. Section 2 introduces the structure and strain gauges distribution scheme of the sensor. Section 3 presents a method and result of the calibration test. Section 4 describes the experiments on a vehicle. Section 5 is the conclusion of this paper.

2. Design of the Sensor

As is shown in Figure 3, the sensor was designed to installed between brake and rim. To match the installation, an adapter was used. Figure 4 shows the shape of the sensor, where strain gauges are pasted on beams. The max diameter of sensor is 194*mm* and its max thickness is 18*mm*. It's measuring range is $F_x = -10kN \sim 10kN, F_y = -10kN \sim 10kN, F_z = 0 \sim 10kN$.

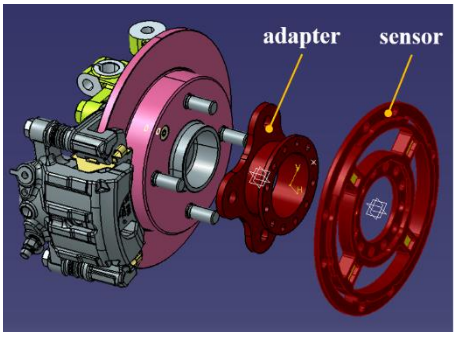

Figure 3: The installation position of sensor

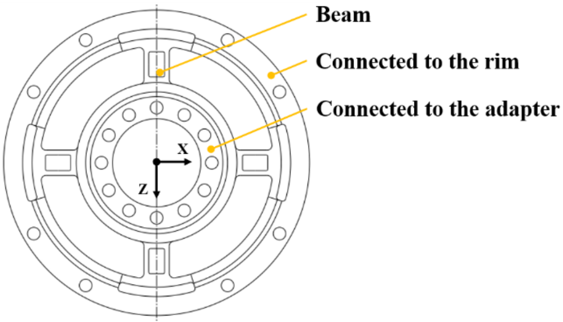

Figure 4: The shape of sensor

To determine the best strain gauges distribution scheme, virtual calibration was carried out by using Abaqus software. [5~6] Figure 5 shows the simulation result when loading $F_x = 10kN$. Figure 6 shows the best strain gauges distribution scheme, where only strain gauges on beam 1 are shown, and strain gauges on other beams are the same.

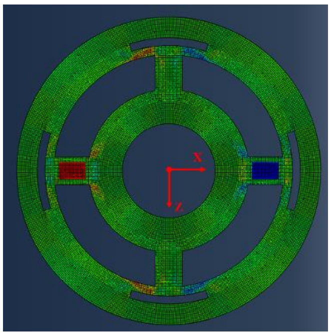

Figure 5: Simulation result when loading $F_x = 10kN$

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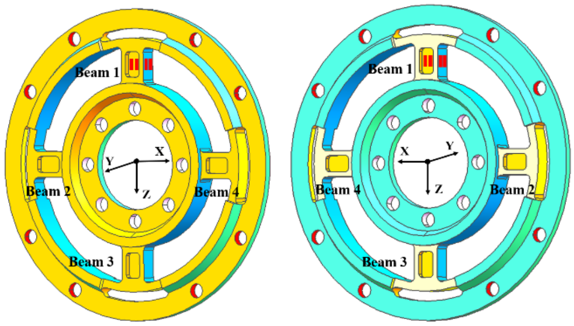

Figure 6: The best strain gauges distribution scheme (on beam 1)

Table 1: Micro strain of output channel under F_x, F_y and F_z

Load →	Fx=10 kN		Fy=10 kN		Fz=10 kN		Mx=1500Nm		My=1500Nm		Mz=1500Nm	
Crosstalk ↓	Micro strain	Crosstalk (%)	Micro strain	Crosstalk (%)	Micro strain	Crosstalk (%)	Micro strain	Crosstalk (%)	Micro strain	Crosstalk (%)	Micro strain	Crosstalk (%)
Fx	303.634	\	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
Fy	0.000	0.00	298.014	\	0.000	0.00	0.000	0.00	0.000	0.00	0.000	0.00
Fz	0.000	0.00	0.000	0.00	303.634	\	0.000	0.00	0.000	0.00	0.000	0.00

Table 1 shows the virtual calibration result under this scheme. In fact, when fixed on a vehicle, the sensor will transmit three forces and three moments, including F_x, F_y, F_z, M_x, M_y and M_z, so moments were also loaded during virtual calibration. Simulation result shows no crosstalk from all forces/moments to F_x, F_y and F_z.

3. Calibration experiment

According to the simulation result, a sensor entity was fabricated (as is shown in Figure 7). To get the relationship between the load and the output voltage signal, the calibration experiment was carried out by using self-developed calibration device.

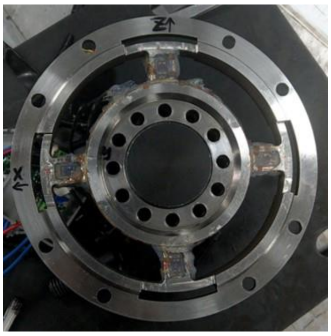

Figure 7: Sensor entity

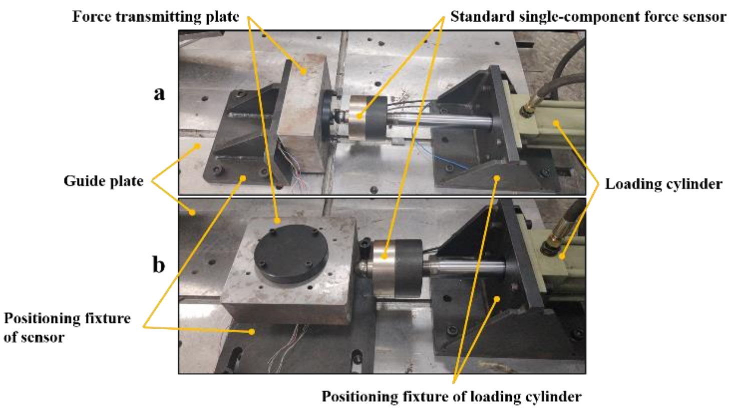

Figure 8: The construction of calibration device

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Figure 8 shows the construction of calibration device, where figure a is the structure when loading F_y and figure b is the structure when loading F_x and F_z. The sensor was fixed between positioning fixture of sensor and force transmitting plate. [7] To guarantee the centrality of the loading and sensor, a stainless steel ball was provided between standard single-component force sensor and force transmitting plate. Every load was loaded in ten steps, and each step increased $1kN$. After that, every load was unloaded in ten steps, and each step decreased $1kN$.

To inspect the influence of moments, eccentric loading calibration experiment was carried out, as shown in Figure 9. In this way, the output voltage was the result of one force and one moment. The result displayed little difference compared with that in centric loading calibration experiment, which meant that moments had little influence on forces, so only centric loading calibration result was shown here. The calibration result is shown in Figure 10 to Figure 12.

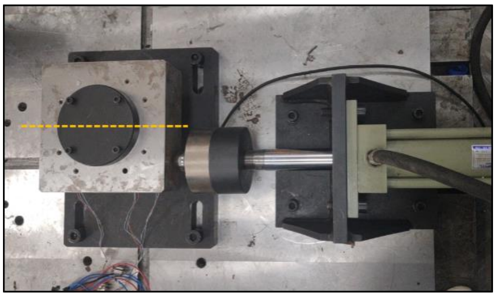

Figure 9: The construction of calibration device (eccentric)

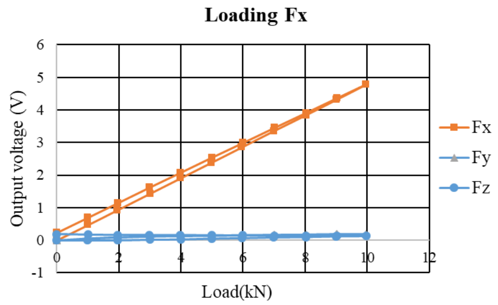

Figure 10: Calibration result when loading F_x

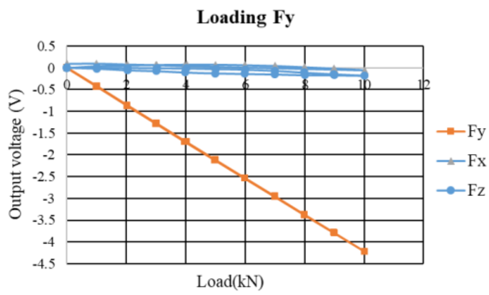

Figure 11: Calibration result when loading F_y

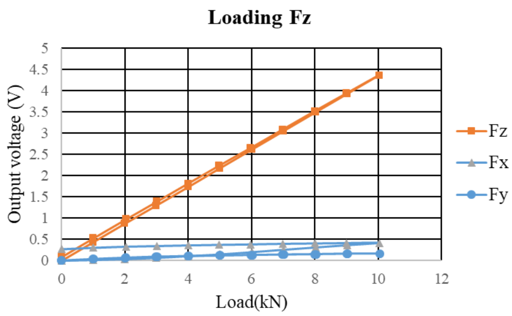

Figure 12: Calibration result when loading F_z

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Liner fitting was used to get calibration coefficient. The relationship between loads and output voltages is shown as follows.

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} 2.090 & 0 & 0 \\ 0 & -2.376 & 0 \\ 0 & 0 & 2.293 \end{bmatrix} \begin{bmatrix} U_1 \\ U_2 \\ U_3 \end{bmatrix} \tag{1}$$

Where U_1, U_2, U_3 are the output voltages of F_x, F_y, F_z channels. Equation 1 will be used to calculate the forces of tires under test.

4. Vehicle experiment

This sensor is aimed to test the real-time forces of tire, which is expected to be used in the increasing of electronic control system performance, so the vehicle experiment was carried out.

Considering the application on vehicle, wireless power and wireless communication were used, as shown in Figure 13 and Figure 14. For the purpose of function test, these two modules were all existing products, so no customized small size or special size were demanded.

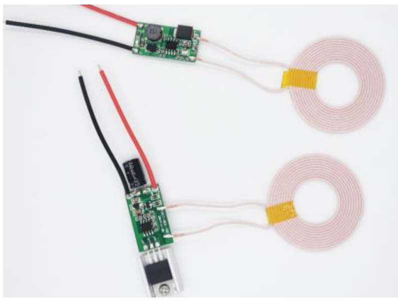

Figure 13: Wireless power supply module

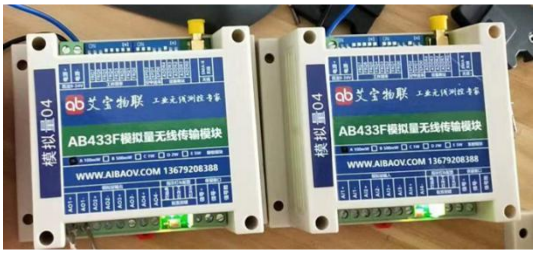

Figure 14: Wireless communication module

When installed on the vehicle, the sensor rotates with the tire, so tire forces need to be calculated through tire rotation angle θ. An angle encoder was selected to get θ. Forces in fixed coordinate taking sensor geometric center as origin are as follows.

$$\begin{bmatrix} F_{x0} \\ F_{y0} \\ F_{z0} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} \tag{2}$$

Where F_{x0}, F_{y0}, F_{z0} are forces in fixed coordinate.

Figure 15: Installation situation of the whole system

Figure 15 shows the installation situation of the whole system. A straight driving experiment at a

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constant speed 10*km/h* was carried out. The output voltages are shown in Figure 16 to Figure 18.

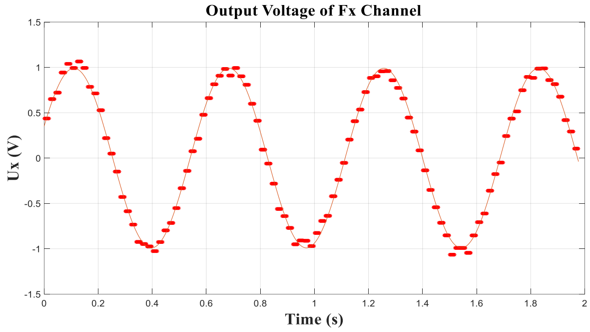

Figure 16: Output voltage of F_x *Channel*

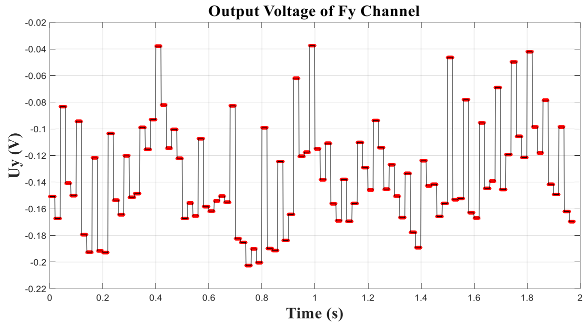

Figure 17: Output voltage of F_y *Channel*

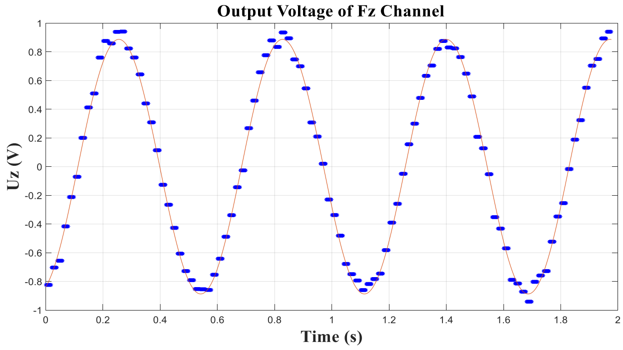

Figure 18: Output voltage of F_z *Channel*

According to equation 2, forces of F_{x0}, F_{y0}, F_{z0} can be obtained. Figure 19 to Figure 21 show F_{x0}, F_{y0}, F_{z0} after filtering. [8~9]

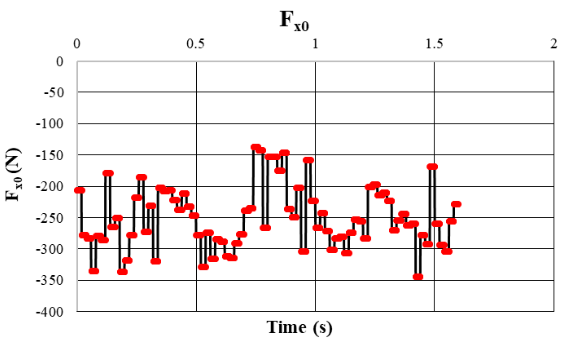

Figure 19: F_{x0}

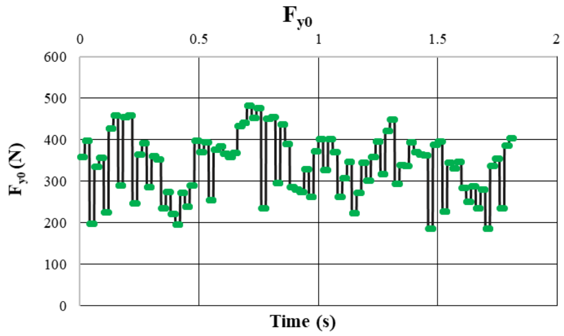

Figure 20: F_{y0}

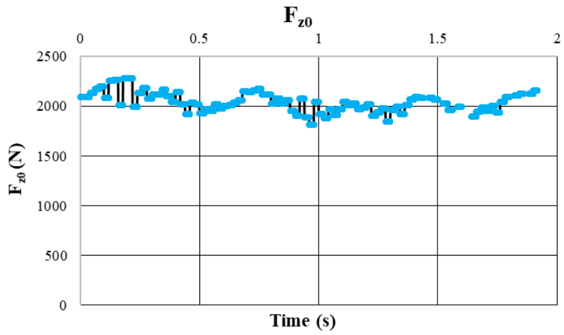

Figure 21: F_{z0}

This tire three-component force sensor was confirmed to be useful to test real-time forces of tires on vehicle. In this paper, forces taking sensor geometric center as origin were obtained. Forces at contact point can be obtained according to the position relation between sensor geometric center and contact point.

5. Conclusions

In this study, a tire three-component force sensor that can test real-time forces of tires on vehicle was developed, which is useful to increase electronic control system performance. [10] With small size and low cost, it offers a new way of developing intelligent tire.

There are still some inadequacies in this study. Although the thickness of this sensor is very thin, more than 36 *mm* was added on the original tire tread. Also, with wireless power and wireless communication, the angle encoder still made the construct complex.

In future work, the following improvements will be made:

a) Customized wireless power and wireless communication will be used to simplify the structure of this sensor.

b) Cooperation with rim suppliers will be started, to make no lengthening on original tire tread with minor changes on rim shape.

c) Cooperation with automobile enterprise will be started, to get tire rotation angle without using an angle encoder.

d) Performance of electronic control system with real-time tire forces will be tested on a vehicle. (In fact, simulation by CarSim software and on hardware-in-loop test bench have both been carried out, and tire forces were proved to be effective to increase the performance of electronic control system.)

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Credit authorship contribution statement

Conceptualization, Zuoping Yao and Yonghui Jia; Methodology, Dang Lu; Software, Yanru Suo; Writing – Original Draft Preparation, Zuoping Yao; Writing – Review & Editing, Baolv Wei; Project Administration, Yonghui Jia; Funding Acquisition, Dang Lu.

Declaration of Competing Interest

There are no conflicts to declare.

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References

[1] Guo, K.H., Liu, Y.B. and Yang, Y., Development on tire test technology and prospect of its application in automobile performance research. Automobile Engineering, (in Chinese), 1990(01):3-11.
[2] Gobbi M, Botero J C, Mastinu G. Improving the active safety of road vehicles by sensing forces and moments at the wheels[J]. Vehicle System Dynamics, 2008, 46:957-968.
[3] http://www.msc-cn.com/products/transducers/wheel-force-transducers/nggallery/galleries/LW12.8-50-1?url=products/transducers/wheel-force-transducers
[4] https://www.kistler.com/zh/product/type-9266a1/?application=14
[5] Gao Fei, "Numerical calculation and analysis of a six-component force transducer," master's thesis, Transport College, Wuhan University of Technology, Wuhan, 2006
[6] Wang, Zhijun, et al. "Optimal design and experiment research of a fully pre-stressed six-axis force/torque sensor." Measurement 46.6(2013): 2013-2021. doi: 10.1016/j.measurement. 2013.03.003
[7] Chen, Danfeng, A. Song, and A. Li. "Design and Calibration of a Six-axis Force/torque Sensor with Large Measurement Range Used for the Space Manipulator." Procedia Engineering 99(2015): 1164-1170. doi: 10.1016/j.proeng.2014.12.699
[8] Pytka, J., "A Wheel Dynamometer for Off-Road Vehicles Testing," SAE Technical Paper 2008-01-0783, 2008, doi: 10.4271/2008-01-0783.
[9] Wang Dong, "Research on Decoupling Theory and Technology of Automobile Wheel Force Measurement," Ph.D. thesis, School of Instrument Science and Engineering, Southeast University, Nanjing, 2016
[10] Botero J C, Gobbi M, Di Piazza N, et al. On the Reformulation of the ABS Logic by Sensing Forces and Moments at the Wheels [C]// 2007: 265-272.