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Decoupling Analysis of the Tiltable Wheel Load Measuring Plate

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Abstract: Tire force can be divided into normal force and tangential force when the vehicle is in tilting condition, the general load cell can't differentiate these two signals accurately. This paper introduces a portable wheel load measuring plate which is characterized by integrating the strain gauge with the upper platform and can be used in tilting condition. In order to decoupling these signals from component of forces, the structure of the upper platform is optimized and analyzed by commercial FEA software. Experimental results show that the maximal measuring error cause by eccentric load is 1.49 % and the maximal measuring error caused by tilting error is 2.49 %. *Copyright © 2013 IFSA.*

Keywords: Center of gravity plate, Decoup, Structure optimize.

1. Introduction

The center of gravity (CG) position has a significant influence on the security, stability and controllability of the vehicles. Scholars at home and abroad have made several researches on it. Nie Xintian [1] from Nanjing Agricultural University brought out a determination method of the height of tractor mass center on the basis of mass-response method and developed the corresponding theoretic calculate model. Zhong Jing [2] from Zhejiang University of Technology established a centroid measurement system of complex mechanical products based on three-point platform supporting reaction theory. A. Fabbri and G. Molari from Italy developed a swinging platform for farm tractor of narrow wheel to measure its CG position [3, 4]. Mikata Yoshitaka [5] from Japan proposed a method of measuring the CG position of trailer transport container with track scale. But these methods could not used for multiaxial heavy vehicles due to their inaccuracy. CG position measurement of multiaxial heavy vehicles is still an unsolved problem. Therefore, this paper presents a method for CG position measurement of multiaxial vehicle in tilting condition. The general load cell can only be used in horizontal condition, and it can not meet the requirement of measuring precision when used in tilting condition. Multi-axis force/torque sensor can not be used as wheel load measurement device for its small measuring range and large thickness although it can decouple multi-axis force [6]. This paper puts forward a tiltable wheel load measuring plate which can be used in tilting condition, it is characterized by integrating the strain gauge with the upper platform and decoupling in structure.

2. The Structure of Wheel Load Measuring Plate

The wheel load measuring plate is the integration of support, scale body and measuring element. A large rectangular groove is processed on the alloy sheet along its width direction, the remaining metal body at the both ends of measuring plate will be used as the support, then the alloy sheet will be a weighbridge. We process 4 long rectangular grooves of the equal depth and equal width which are parallel to the support, we symmetrically paste uniaxial resistance strain gauges of equal distance which are vertical to the support in the long rectangular grooves, the valid load-bearing area is the region between the two inner rectangular grooves, as shown in Fig. 1.

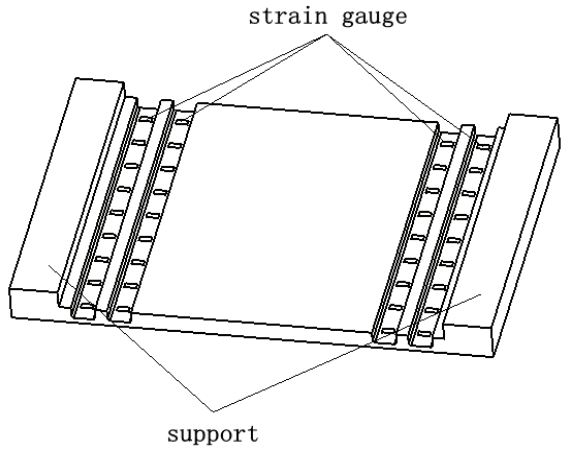

Fig. 1. The plate's structure

The structural characteristics of measuring plate are as follow:

1) The plate's upper part work as both loading platform and elastomer, the strain gauge is equivalent to measuring element, the measuring plate is the integration of support, scale body and measuring element, and it has advantages of compact structure, small thickness, light weight, easy installation and portability.

2) Measuring plate is an integration structure which has no movable elements, thus it has high resistance to shock and shake. The dynamic components caused by interference are small in measuring process, reducing the performance requirements of measuring instruments.

3) In tilting condition, the measurement result is only relevant to normal force, but irrelevant to the position of normal force and tangential force. It can achieve the decoupling of tangential force.

3. The Influence of Structural Factors on the Measurement Results

3.1. Evaluation Parameters and Loading Mode

The simulation of the measuring plate in horizontal and tilting condition is made by ANSYS in this paper, verifying the influence of structural factors on measuring results under the same loading mode. Especially, simulation analysis in tilting condition is made by using different tangential force F_x to simulate different tilt angle, as shown in Fig. 2 and Fig. 3. Finally, comparing the analysis results with the results in horizontal condition.

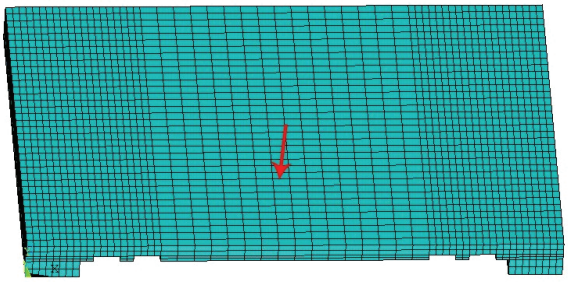

Fig. 2. The simulation in horizontal condition.

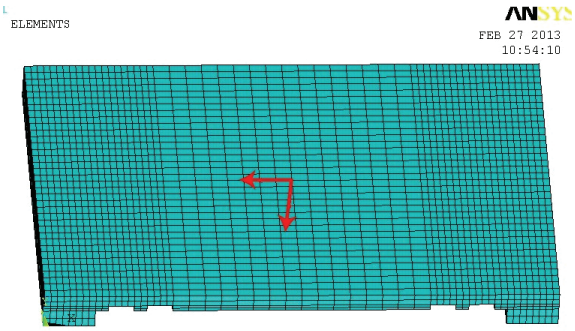

Fig. 3. The simulation in tilting condition.

The performances of measuring plate mainly contains anti eccentric load and anti tilt. In this paper, we use the maximum eccentric load error and tilt error to evaluate the performances.

The maximum eccentric load error:

$$e_i = \max\left(\frac{\varepsilon_i - \bar{\varepsilon}}{\bar{\varepsilon}} \times 100\%\right) \ (i=1,2\ldots9), \qquad (1)$$

where ε_i is the strain output value at *i* loading point; $\bar{\varepsilon}$ is the strain value's arithmetic mean of each loading point.

The maximum tilt error:

$$e_\alpha = \max\left(\frac{\varepsilon_\alpha / \cos\alpha - \varepsilon_0}{\varepsilon_0} \times 100\%\right) \qquad (2)$$
$$(\alpha = 0,5,10\ldots,35),$$

where α is the tilt angle of the plate; ε_α is the strain value in α; ε_0 is the strain value in 0°.

The tilting condition loading is shown in Fig.4, and strain nephograms for various action areas in Fig.5-7.

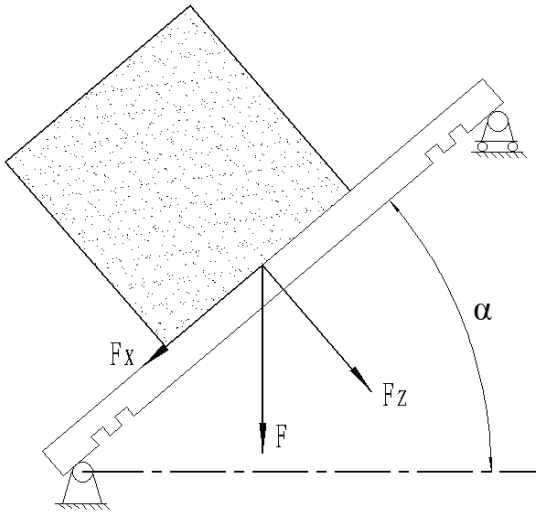

Fig. 4. The tilting condition loading.

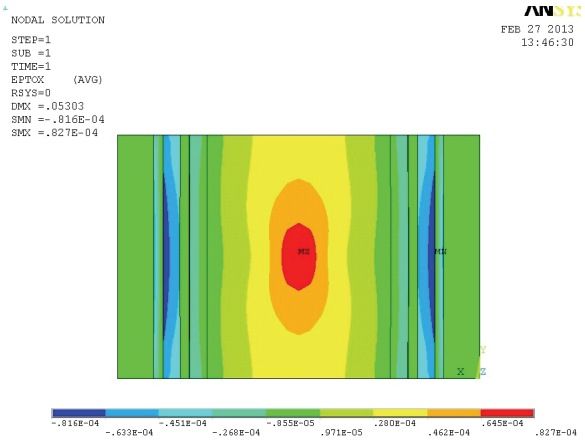

Fig. 5. Strain nephogram with 750 mm^2 action area and 980 N load.

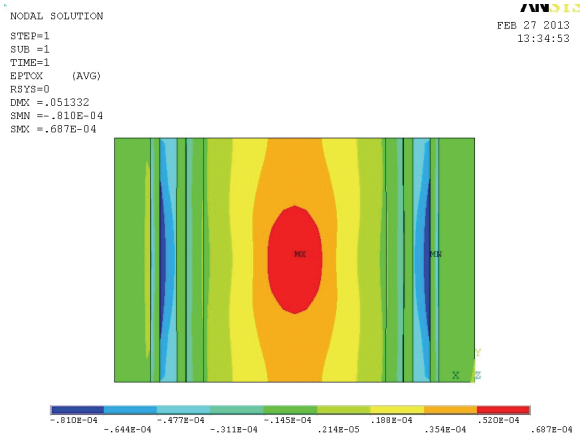

Fig. 6. Strain nephogram with 22550 mm^2 action area and 980 N load.

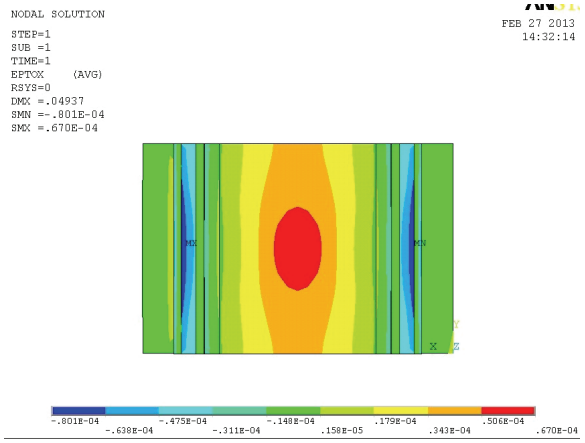

Fig. 7. Strain nephogram with 4500 mm^2 action area and 980 N load.

The simulation of measuring plate is made in horizontal and tilting condition when point and surface force are loaded separately. Simulation results show that the load area will not affect the output of the measuring plate as long as the size and the center of the load is certain, as shown in Fig. 8, this show that the measuring plate can measure the load of wheels of different sizes.

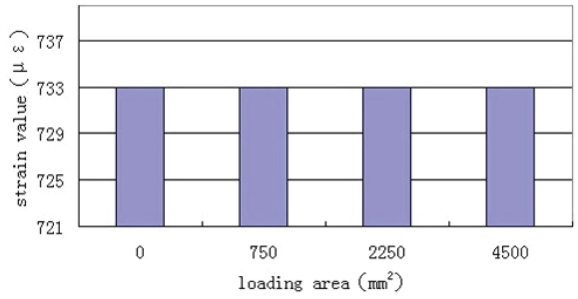

Fig. 8. Simulation diagram of 980N load on the area of different sizes with the same loading center.

3.2. The Influence of Structural Factors on the Measuring Plate

To improve the measurement accuracy, simulation analysis is made by the commercial FEA software ANSYS to find out the influence of structural factors on the measurement results. As shown in Fig. 9, the structural factors we take into account are as follow:

1) h---the depth of long rectangular groove;
2) d---the width of long rectangular groove;
3) l---the space between two long rectangular grooves;
4) n---the number of the strain gauge in each rectangular groove;
5) w---the width of measuring plate.

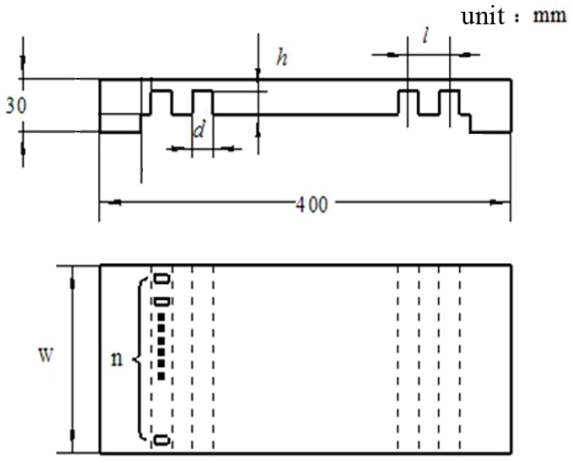

Fig. 9. The structural factors.

The trend of the maximum eccentric load error and tilt error along with different h is shown in Fig. 10. With the increasing of h, the eccentric load error and tilt error will decrease, the strain in rectangular groove region will increase, the maximum load quantity also will decrease. Resulting in reduction of the plate's measuring range.

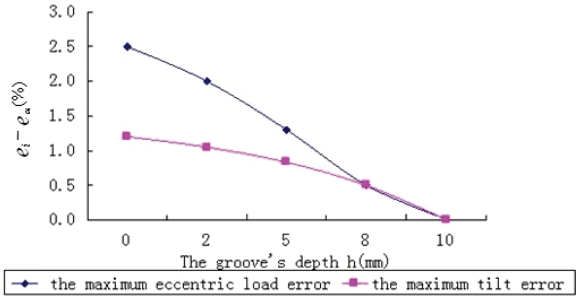

Fig. 10. The relation between groove's depth and measurement result.

The trend of the maximum eccentric load error and tilt error along with different d is shown in Fig. 11. Long rectangular groove's width has less effect on the eccentric load error.

On the contrary, the tilt error will increase along with increasing of long rectangular groove's width. The strain gauge is pasted on the surface of the four rectangular grooves, the width of rectangular groove should be appropriate, otherwise it will be difficult to paste strain gauge.

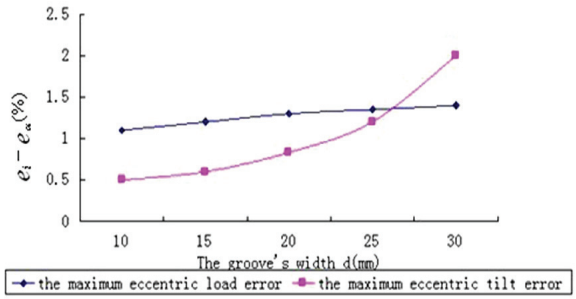

Fig. 11. The relation between groove's width and measurement result.

The trend of the maximum eccentric load error and tilt error along with different l is shown in Fig. 12.

The tilt error will increase with the increasing of l, but the eccentric load error will decrease, if other factors remain constant, two long rectangular grooves' space will increase, resulting in the reduction of valid load-bearing area.

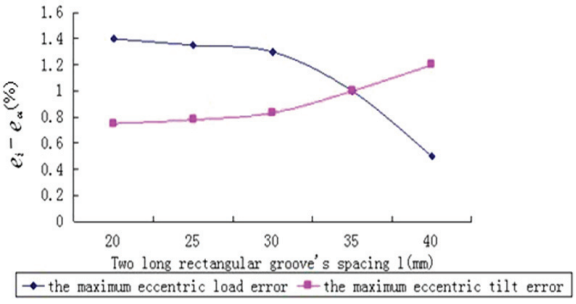

Fig. 12. The relation between two long rectangular grooves' space and measurement result.

The trend of the maximum eccentric load error and tilt error along with different n is shown in Fig. 13. The eccentric load error and tilt error will decrease along with the increasing quantity of the strain gauge in each rectangular groove. too many strain gauges will lead to the increasing of the disturbance among Wheatstone bridges.

What's more, the rectangular groove's length is limited, so the quantity of the strain gauge should be appropriate.

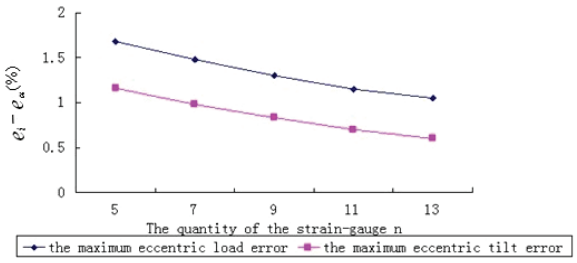

Fig. 13. The relation between the quantity of the strain gauge and measurement result.

The trend of the maximum eccentric load error and tilt error along with different w is shown in Fig. 14. With the increasing of w, the distribution density of strain gauges will decrease relatively, then the eccentric load error and tilt error will increase apparently. But the valid load-bearing area will decrease with the decrease of w.

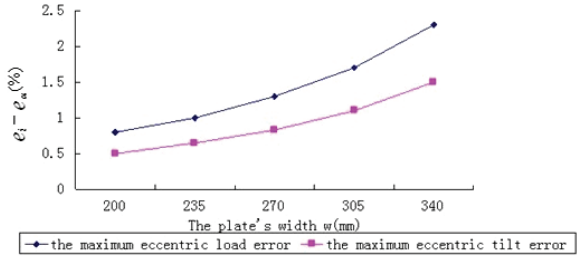

Fig. 14. The relation between the plate's width and measurement result.

In conclusion, according to the influence of the structural factors, processing and patch feasibility on the measurement result, we determine the plate's size. As shown in Table 1.

Table 1. The optimized structural parameters.

Factors	h(mm)	d(mm)	l(mm)	n	w(mm)
Size	5	20	30	9	270

4. Experimental Verification

As shown in Fig. 15 and Fig. 16, according to the structure size above, we product a specimen of the measuring plate, and conduct the experiment calibration of the plate.

We chose 9 different loading positions, the tilt angle is from 0° to 35° and the loading quality is from 0 to 300 kg, then we do the experiments repeatedly between the up stroke and down stroke, the curve fitting of experimental data is established by MATLAB, the equation is as follow:

$$y = 7.223x - 0.313, \tag{3}$$

where y is the output value of strain, x is the input value of mass.

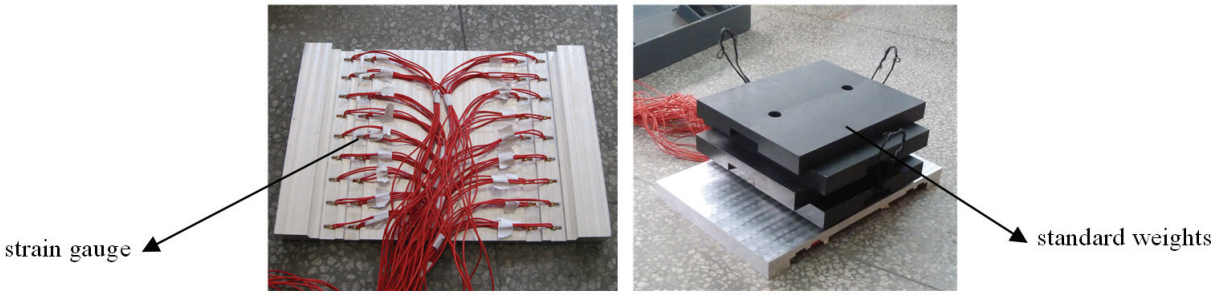

Fig. 15. Horizontal loading.

Fig. 16. Tilting fixture and cabinet.

By analyzing the experimental data, we find that the errors coming from the simulation and experiment are inconsistent, this is because of the influences from measurement error of measuring instrument, model processing accuracy, pasting of strain gauges, experimental temperature and humidity, etc.

As shown in Fig. 17 and Fig. 18 maximum eccentric load error is the maximum value of relative deviation, it reflects the anti eccentric load performance of measuring plate. Tilt error is the maximum relative deviation between the strain value converted into one of horizontal condition with the trigonometric function under different tilt angle and the strain value in horizontal condition, it reflects the anti tilt performance of measuring plate. By processing the experimental data, we obtain that the maximum eccentric load error is 1.49 % and maximum tilt error is 2.49 %. It indicates that the measuring plate has excellent performance of anti eccentric load and anti tilt and meets the measurement requirement.

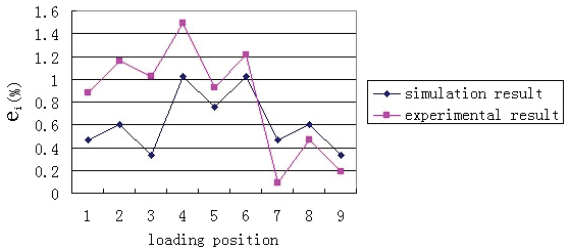

Fig. 17. Simulation and experimental eccentric load error.

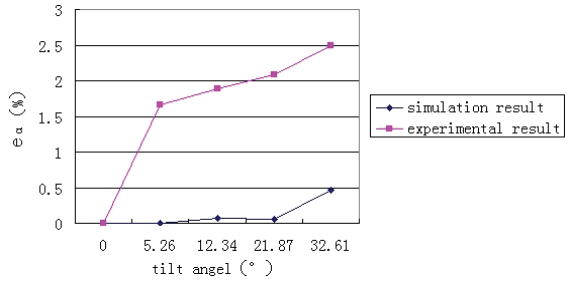

Fig. 18. Simulation and experimental tilt error.

5. Conclusion

This paper studies on the structure of the tiltable wheel load measuring plate, the structure size is optimized by finding out the relation between structural factors and measurement error, the experimental verification has been conducted on the specimen. The experimental results show that the measuring plate can achieve decoupling and can be used in tilting condition.

Acknowledgements

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