Research on Verifying the Accuracy of Finite Element Analysis on the Steel Strips of Boneless Wipers

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Abstract. In order to verify the accuracy of finite element method for detecting the strain distribution trend on steel strips of boneless wipers, a series of measures were taken. The strain values of eight points evenly distributed on the upper surface of a steel strip were measured experimentally. A finite element analysis of the model of a steel strip was performed using ANSYS 18.0 to obtain the strain values of these eight points. Comparing the simulated strain values with the experimental measurements, it is found that the distribution trends of two is consistent, but the simulated strain value of each point is much smaller than the experimental measurement. The reason for this error is that the influence of the self-gravity of a steel strip in the experiment was not eliminated. In future research, the experimental method should be improved to eliminate the influence of the self-gravity of steel strips on the experiment.

Keywords: Finite element analysis; Experiment; Strain; ANSYS 18.0; Steel strip of boneless wiper.

1. Introduction

Wiper is a device that plays an important role in ensuring a vehicle driver’s view by removing rain or dirt from a windscreen with a rubber blade that moves back and forth over the glass [1]. According to the structure, wipers can be divided into bone wipers and boneless wipers. Boneless wipers are studied in this paper. The steel strip is an important part of boneless wiper. The irrational design and structure of steel strip makes the strain distribution uneven when the wiper is in operation, resulting in poor wiping effect and low service life. Therefore, it is necessary to improve the existing steel strips and use a suitable method to detect the strain distribution of the improved steel strips.

In order to improve the performance of the existing wiper system, scholars at home and abroad have done some related researches. Based on the MCU of STC12C5616AD, Yanyan Wang et al. [2] designed an intelligent infrared windscreen wiper based on infrared rain sensor. The experiment results show that the system they design is sensitive and reliable. M. Unno et al. [3] used a combination of theory and experiment to ascertain the details of the behavior of the wiper blade for the purpose of reducing noise generated by automobile windshield wipers during reversals. The results show that the theoretical predictions are in good agreement with experimental observations. Evgeny Ageev et al. [4] developed an alternative method consisting in the use of a protective cover plate in order to protect those windshield zones that are most subject to cracking. The results show that the cover plate does not obstruct the vision, such protective cover plate has a long service life, the service
life of the new protective cover is at least a year if recommendations for installation and operation have been observed. However none of their research involved the steel strips of boneless wipers, and there is almost no literature on this. Therefore, for the purpose of verifying the accuracy of finite element method (FEM) for detecting the strain distribution on steel strips, this paper carried out experiments and finite element simulations on a steel strip, and obtained the experimental strain values and simulated strain values of eight points evenly distributed on the upper surface of this steel strip. If the simulated strain values of these eight points are close to those measured by experiments, then in future research, FEM can be used instead of experiments to detect the strain distribution of steel strips, thereby speeding up the development of new wiper products and saving research and development costs. The FEM has previously been used successfully on prototyped objects for several years [5] but still needs to be proven to be successful on the steel strips of boneless wipers.

2. Experimental Design

2.1. Experimental Boundary Condition

Shown in Figure 1 is the schematic diagram of the experimental boundary conditions. This is set according to the actual mechanical conditions of the steel strip of boneless wiper operating on the car. The leftmost end of steel strip is constrained to six degrees of freedom in Ux, Uy, Uz, Rotx, Roty and Rotz. The rightmost end of steel strip is constrained to the degree of freedom in Uy. A certain amount of force is applied in the middle of steel strip along the negative direction of the Y-axis.

![Figure 1. Schematic diagram of the experimental boundary conditions.](image)

2.2. Experiment Process

The experimental device includes: a vertical pressure test bench, a steel strip of boneless wiper, a strain detection system, and a host computer platform. Its real shot is shown in Figure 2, and the schematic is shown in Figure 3. The vertical pressure test bench is the HLD hand-cranked vertical test bench to apply pressure and display its value. The strain detection system and host computer platform are the HP-DJ8X25 signal acquisition platform to detect and record strain values. The strain gauges are foil-type strain gauges connected by half-bridge. During the experiment, the vertical pressure test bench applied pressure on the middle of a steel strip to deform it. As the pressure increased, the host computer recorded the strain values of eight points evenly distributed on the upper surface of a steel strip, the data acquisition program interface of the host computer is shown in Figure 4. When the applied pressure reached 2.4N, the strain values of these eight points were collected by host computer. In order to eliminate the random error of the strain detection system, the same experiment was done eight times, and the experiment results were averaged.
2.3. Experimental Results
The experimental results are shown in Table 1.

Table 1. Experimental results.

| No. | No.1[με] | No.2[με] | No.3[με] | No.4[με] | No.5[με] | No.6[με] | No.7[με] | No.8[με] |
|-----|----------|----------|----------|----------|----------|----------|----------|----------|
| 1   | -232.8   | -520.6   | -931.6   | -1325.0  | -1300.1  | -936.5   | -514.9   | -237.5   |
| 2   | -234.5   | -518.9   | -933.4   | -1327.7  | -1297.2  | -939.3   | -512.6   | -240.8   |
| 3   | -233.8   | -521.0   | -930.5   | -1324.6  | -1303.6  | -938.7   | -516.5   | -239.5   |
| 4   | -235.6   | -520.9   | -934.7   | -1322.0  | -1301.4  | -933.8   | -515.3   | -236.2   |
| 5   | -231.7   | -519.8   | -932.5   | -1327.4  | -1298.3  | -937.5   | -513.2   | -238.6   |
| 6   | -236.7   | -523.7   | -935.3   | -1326.2  | -1302.8  | -934.3   | -519.5   | -237.0   |
| 7   | -230.5   | -518.4   | -930.8   | -1327.5  | -1303.0  | -935.4   | -515.2   | -238.5   |
| 8   | -233.5   | -519.8   | -932.5   | -1324.7  | -1299.7  | -940.8   | -517.4   | -240.5   |
| X   | -233.6   | -520.4   | -932.7   | -1325.6  | -1300.8  | -937.0   | -515.6   | -238.6   |

Note: με: strain is the ratio of the deformation variable to the original size, expressed by ε, that is, ε = ΔL / L, dimensionless, commonly used as a percentage; micro-strain is also used to indicate the degree of change in deformation, but it is only used to describe extremely small deformation. Expressed by με, 1 με = (ΔL / L) * 10^(-6), that is, ε = 10^6 * με, that is, microstrain is one millionth of strain. This unit is also used in Table 2 and Table 3 below.
3. Finite Element Analysis

3.1. Element Type and Material Properties
The element type selected for the finite element analysis is solid186. The material of steel strip is SK5 steel. The mechanical properties of this material are: the density is 7.85g/cm³, the modulus of elasticity is 2.1e5Mpa, the Poisson's ratio is 0.3. The software used for finite element analysis is ANSYS 18.0.

3.2. Modeling
The three-dimensional model of steel strip is established by using the stretching command as shown in Figure 5. It is strictly modeled according to the actual size.

3.3. Meshing
Sweeping method is used to generate meshes and setting the minimum element size to 1mm for meshing. The meshed model has 72224 nodes and the number of units is 9968. The overall grid is shown in Figure 6, and the partially enlarged grid in the middle is shown in Figure 7.

3.4. Applying Boundary Conditions
The simulation boundary conditions should be the same as the experimental boundary conditions in Figure 1. The 33 nodes at the lower left end of steel strip model are fixedly constrained, the 33 nodes at the lower right constrain the degree of freedom in the Y-axis direction, and the 17 nodes in the middle of the upper surface apply a force of 2.4 N in the negative direction of the Y-axis. The boundary conditions applied on the model of steel strip are shown in Figure 8.
3.5. Simulation Results

The strain cloud diagram of model of steel strip obtained by solving is shown in Figure 9. The corresponding node numbers of the eight points in the experiment are: 17334, 19097, 20860, 22623, 24386, 26149, 27912, 29675. The strain values and X coordinates of these 8 nodes are shown in Table 2.

Comparing the simulation results of these eight points from Table 2 with the measured results from Table 1, an error analysis is performed and shown in Table 3.

Table 2. Simulation results.

| Node Number | 17334 | 19097 | 20860 | 22623 | 24386 | 26149 | 27912 | 29675 |
|-------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Strain Value[με] | -103.1 | -313.6 | -527.4 | -743.4 | -743.4 | -527.4 | -313.6 | -103.1 |
| X Coordinate[mm]  | 252.63 | 184.7 | 112.8 | 37.97 | -37.97 | -112.8 | -184.7 | -252.63 |

Table 3. Error analysis.

| Experimental Strain Value[με] | Simulation Strain Value[με] | Relative error |
|--------------------------------|-----------------------------|----------------|
| No.1  -233.6 | -103.1 | -0.559 |
| No.2  -520.4 | -313.6 | -0.397 |
| No.3  -932.7 | -527.4 | -0.435 |
| No.4  -1325.6 | -743.4 | -0.439 |
| No.5  -1300.8 | -743.4 | -0.429 |
| No.6  -937.0 | -527.4 | -0.437 |
| No.7  -515.6 | -313.6 | -0.392 |
| No.8  -238.6 | -103.1 | -0.568 |
4. Conclusion
Comparing the simulation results with the experimental results, it is found that: 1. The strain distributions of the two are consistent: that the maximum strain value exists in the middle position, the other strain values gradually decrease from the middle to the left or right, and the strain values are symmetrically distributed along the middle. 2. The simulated strain value at each point is much smaller than the experimentally measured value. The simulated strain value distribution trend is consistent with the experimental measurement, and the distribution law conforms to the general physical characteristics, which shows that the finite element analysis method is feasible. The large difference between the simulated strain value and the experimental measurement is because the steel strip in Figure 4 receives its own gravity in addition to the downforce applied by the vertical pressure test bench in the experiment and steel strip is very sensitive to deformation. In the simulation, only the downforce applied by the pressure test bench is applied to the boundary conditions without considering gravity. Then the deformation of simulation model is smaller than the actual object in the experiment, and the larger the deformation, the greater the strain. Therefore, the simulated strain values are all smaller than the experimentally measured. In future research, the experiment should place steel strip on the experimental table with the side as bottom, and use a horizontal pressure test bench instead of the vertical pressure test bench in this paper to apply pressure to steel strip. In this case, as shown in Figure 1, steel strip in the negative direction of the Y-axis is only subjected to the pressure applied by horizontal pressure test bench and is not affected by its own gravity. Comparing the simulation results and experimental results under the same boundary conditions again to see if they are close to verify the accuracy of the finite element method for detecting the strain distribution on steel strips. Both the simulation and experiment of the steel strips of boneless wipers should be designed to be closer to the real scene of its operation in a car.

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References
[1] Sang Hwan Lee, Young Heon Kim, Jisu Sung, Kum Cheol Shin, Je Hoon Oh 2013 Investigation of the contact force distribution and dynamic behavior of an automobile windshield wiper blade system Journal of Automobile Engineering vol 227 (America: SAGE) pp 1040-1052
[2] Yanyan Wang, Jian Wang, Zhifu Zhu 2011 Design of Intelligent infrared Windscreen Wiper based on MCU Procedia Engineering vol 15 (Amsterdam: Elsevier) pp 2484-2488
[3] M. Unno, A. Shibata, H. Yabuno, D. Yanagisawa, T. Nakano 2017 Analysis of the behavior of a wiper blade around the reversal in consideration of dynamic and static friction Journal of Sound and Vibration vol 393 (Amsterdam: Elsevier) pp 76-91
[4] Evgeny Ageev, Sergey Pikalov, Anton Pereverzev 2018 Methods for improving the operational reliability of a car windshield Transportation Research Procedia vol 36 (Amsterdam: Elsevier) pp 2-8
[5] D.W. Abbot, D.V.V. Kallon, C. Anghel, P. Dube 2019 Finite element analysis of 3D printed model via compression tests Procedia Manufacturing vol 35 (Amsterdam: Elsevier) pp 164-173