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The Prediction Analysis of Flat Tire Vehicle Motion Response under Turning

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***Abstract* – In order to study the vehicle motion response under the condition of high speed puncture when turning, Based on the Chery QQ car, made a turn driving road test, Using the multivariate regression principle and with the aid of SPSS software, the regression equation is established that among the most sensitive and second sensitive driving stability parameters with tire pressure and speed on the basis of the statistical analysis of data, and the feasibility of the model is verified based on this model predict the vehicle motion response under the condition of high speed flat tire, It turned out that when the speed of 120km/h, lateral acceleration of the most sensitive parameter can reach to 7.868 ($m\cdot s^{-2}$) at the inside wheel puncture, but maximum roll angle of the most sensitive parameters can reach to -3.590(°), The inside wheel flat tire makes trend of steering yaw heavily, which can bring drift and slip. The outside wheel puncture is benefit to driving straight but there will be rollover. Moreover, according to our research, we know that the inside of front wheel flat tire is the most dangerous situations.**

***Keywords* – Sensitive Parameter, Regression Model, Flat Tire Prediction, Motion Response.**

I. INTRODUCTION

With the development of China's auto industry and car ownership increasing, traffic accidents happened more and more. All the causes of road traffic accidents, the sudden puncture at high speed is most important. Serious consequences make people attaches great importance to the car driving safety. At home and abroad mainly for a vehicle motion response and stability control research, Such as : making the simulation test of high-speed vehicle tire blew the ZBIGNIEWL [1], major in vehicle dynamics modeling with tire blowout, and the accuracy of the model was verified by real vehicle experiment, using the model for all kinds of working conditions of puncture test, through the analysis of test data to get the basic characteristic of the flat tire vehicle motion, which provides guidance the flat tire vehicle active safety control technology research.

In China, Tongji University established 12 degrees of freedom model which was used to study the abnormal tire pressure and the relationship between the vehicle parameters. Through the vehicle control stability experiment , obtained that the Lateral acceleration of vehicle and yaw velocity is the most sensitive to changes in tire pressure state parameter [2].But this conclusion is only obtained at the speed of 60 km/h , not in other speed,

which has some imperfection; In the study of vehicle motion response after puncture, more scholars both at home and abroad by dragging a blowout vehicles or using the software simulation to study the related performance, the data has certain gap compared with real vehicle test. In the flat tire safety control aspect, some scholars research it through the change of stability parameter , achieved good control effect, but the control parameters selection is relatively single, have some limitations.

In literature [3],studying four stability parameters, the vehicle experiment is carried on the Chery QQ car under turning condition by different speeds and different position car tire pressure reducing method, which solved the limitations of single control parameters and avoid the risk of the real car flat tire experiment, established the relationship among tire pressure the stability, the vehicle speed , and then get the most sensitive stability parameter to changes in tire pressure. According to security reasons, in the literature [4], the lowest tire pressure is 60 kPa, the highest test speed is 60 km/h, and studying the impact of the tire pressure change under the condition of high speed on vehicle driving stability is more meaningful to improve the car safety.

Based on the research methods and conclusions in the literature [5,6], using SPSS software to establish the forecast model of the sensitive parameters and forecast response of the vehicle under a flat tire on high speed, which provides the reference for researching stability control strategy of flat tire vehicle .

II. EXPERIMENT

2.1 The stability parameters of driving vehicle

The vehicle's driving stability is that in the process of driving under the influence of external factors, the ability of making the vehicle keep moving status and direction, controlling the car to avoid the accidents such as sideslip and rollover. In the process of the vehicle, yaw angular velocity and lateral acceleration are reflected in the vehicle longitudinal and lateral stability of the vehicle. Moreover if the roll angle exceeds a certain threshold, easily lead to vehicle rollover, may also influence the driving stability of vehicle, it is often the lateral acceleration, yaw angular velocity and roll angle as the impact of automobile running parameters of the stability test. Under normal circumstances, vehicle tire pressure normal driving straight to tie rod less stress and maintain in certain range (25 N to 30 N), and when the high speed vehicle blowout occurs, the direction of travel will inevitably produce deflection, and steering tie rod stress would occur great changes [3]. Therefore, steering tie rod force is an important factor to study the influence of tire pressure change on driving stability. Based on the analysis above, the four parameters, yaw velocity, lateral acceleration, roll angle and the force of steering tie-rod, can reflect the state of the motion of the vehicle, and can be the parameter index used to estimate whether a moving vehicle is in a stable state.

2.2 Test conditions

The vehicle's total deadweight is 1300 kg, front axle load is 800 kg and rear axle load is 500 kg; Standard tire pressure is 210 kPa; the asphalt pavement is about 4000 m long , 25 m wide; vehicle-mounted members are 3 people. In this experiment, set tire pressure drop rate is about 20%, test tire pressure change, respectively 210, 168, 135, 168, 135 and 60 kPa. For security reasons, the speed range is set to 20-60 km/h, all test conditions for the right moving test. In addition to test tires, the tires are kept as a standard tire pressure. Test, according to the inside of the front wheel, the inside of the rear wheel, the outside front wheel and the outside rear wheel in the order of specified for tire pressure drop test; The preservation of the test, the test data and export through own DEWE soft DEWE-2610 acquisition instrument data processing software to complete [7,8]. Test collection site and DEWE-2610 is shown in figure 1 and figure 2 .

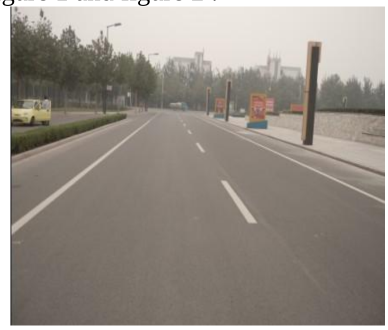

Fig.1. Proving ground

Fig.2. DEWE-2610

III. Establishment and Test of Prediction Model

3.1 Establishment of sensitivity parameter prediction model

It is linear relation between vehicle driving stability parameter which contain lateral acceleration, yawing angular velocity, roll angle, tie rod force and the tire pressure. The lateral acceleration is the most sensitive when inside car tire pressure changes, yawing angular velocity is weaker than lateral acceleration. The roll Angle changes is the most sensitive when pressure change of the outside tire pressure reduce to less than 40% [3]. The lateral acceleration, yawing angular velocity, the roll angle are the dependent variable, tire pressure and speed of the independent is variable, the default value of significance level is *a=0.05*. As shown in table 1,established a sensitive parameter of multivariate linear regression model by using SPSS software.

Lab.1 veering driving stability parameter

Different Wheel	Regression equation
Inside Front Wheel	$a_y = 4.748 + 0.014 * v - 0.018 * \rho$ $\omega = 6.979 + 0.018 * v - 0.019 * p$
Inside Rear Wheel	$a_y = 5.088 + 0.015 * v - 0.016 * p$ $\omega = 7.231 + 0.018 * v - 0.021 * p$
Outside Front Wheel	$\phi = 3.267 + 0.007 * v - 0.008 * \rho$ $\omega = 1.823 - 0.010 * v + 0.013 * p$
Outside Rear Wheel	$\phi = 3.010 + 0.004 * v - 0.007 * p$ $\omega = 2.163 - 0.013 * v + 0.014 * p$

Note: a_y is the vehicle acceleration; ω is the yaw rate; φ is slideslip angle; V is vehicle speed, P is tire pressure.

3.2 Test of sensitivity parameter regression model

After established regression equations, which is not used on analysis and forecast immediately. It takes the test of goodness of fit, significance test, coefficient of inspection and residual normality to show the rationality of the established model[9,10]. Taking an example of the inside front wheel lateral acceleration, having a model inspection.

3.2.1 Goodness of fit test

The test of goodness of fit of the regression model sample data which is often used to adjust R^2 ,which is viewed as a judging criteria of goodness of fit, it is R_a^2 .

$$R_\alpha{}^2 = 1 - \frac{MSE}{MST} = 1 - \frac{SSE/(n-m-1)}{SST/(n-1)} \qquad (1)$$

In the type: *n* as the sample data, *m* as the independent variable number. Its value between 0-1, the closer to 1 indicates the better fitting degree. Adjusting the sample determination coefficient greater than 0.75, which represent the degree of fitting is good.

As is shown in Table 2, it is the goodness of fit of the lateral acceleration of multivariate linear regression model, the adjusted R^2 is 0.904 > 0.75, so the regression equation of the lateral acceleration can be thought as the fitting degree of excellent.

Table 2: Optimal test for multiple linear regression model of lateral acceleration

Model	R	R^2	R^2 Correction	Standard estimation error
1	0.967	0.934	0.904	0.256

3.2.2 The significance test of regression equation

Regression equation of the significance test is mainly used to test whether or not a linear relationship between independent variable and dependent variable, using the linear model to describe the relationship between them is appropriate. F statistic test is commonly used in the regression equation of significance, it is assumed H_0: β_i=0, H_1: $\beta_i \neq 0$.F statistics is:

$$F = \frac{MSR}{MSE} = \frac{SSR/m}{SSE/(n-m-1)} \quad (2)$$

Obey the distribution of the F statistics, including for the regression coefficientsβ_i, the sum of sample data *n*, for the number of independent variables. Under the significance levelα,if $F \geq F_a(m,n-m-1)$,then reject H_0, the linear relationship between the dependent and independent variables and significantly; whereas accept H_0. When the probability P (Sig) value is less than the significance level, should reject the null hypothesis, that the linear relationship between the dependent and independent variables and significantly, whereas no significant linear relationship between independent variable and dependent variable.

Table 3: The lateral acceleration of multiple regression analysis of variance

Parameter	Square sum	Df	Mean square	F	Sig.
Regression	333.199	2	166.600	2531.445	0.000
Residuals	23.495	357	0.066		
Total	356.694	359			

As is shown in table 3, it is the lateral acceleration of multiple regression analysis of variance table, the corresponding Sig. value is 0.000, far less than the significance level, so think that lateral acceleration and the linear relationship between tire pressure and the speed is remarkable which can set up multiple linear regression model.

3.2.3 Significance test of regression coefficient

Significance test of regression coefficient is mainly in order to get rid of no significant impact on the dependent variable of the independent variables. Significance test of regression coefficient is often adopted *t* test. It's assumed H_0: β_i=0, H_1: $\beta_i \neq 0$

Based on the definition of *t* distribution, there is

$$t_i = \frac{\beta_i}{\sigma/\sqrt{n}} t(n-m-1) \quad (3)$$

Among them β_i as the regression coefficient, σ as an unbiased estimator, *n* as the sum of sample data, *m* as the independent variable number. For a given level of significance α here, when$|t_i| \geq t_{\alpha/2}(n\text{-}m\text{-}1)$, then fuse H_0 ,think that influence of independent variable on the dependent variable is significant; whereas accept it. On the other hand, through the output of SPSS software, can be directly obtained test conclusion by *P*(Sig) value compared with the level of significance test results. If the *t* value of each coefficient of the Sig. is less than level of significance, which represent the significant significance.

As is shown in Table 4 ,it is a multiple regression equation coefficient and lateral acceleration of the test result of the regression coefficient. Constant term , the speed of the car, tire pressure constant *t* test statistics of the observed value corresponding to the probablity value of P (Sig) were 0.000, 0.001, 0.000, which are all less than the significance level *a*=0.05, so the regression coefficient have significant difference with 0. That Can well explain the linear relationship among the inside of the front wheel lateral acceleration and tire pressure, the speed of the car.

Table 4: A multiple regression coefficient and lateral acceleration

Parameters	Non-standard coefficient		Coefficient	t	Sig.
	B	Standard error	Beta		
(Constant)	5.948	0.052		109.558	0.000
Tire pressure	-0.022	0.000	-0.946	-69.624	0.001
speed	0.016	0.001	0.199	14.677	0.000

3.2.4 Residuals normality

When the independent variable took the specific values, the corresponding residual must have positive and negative. As a whole, which should obey to zero mean gaussian distribution. Usually use residual cumulative probability graph (P-P) to judge whether the distribution of a variable in a specific distribution of "test". If the two have basically the same distribution, then the point in the P - P figure should be around a slash, if two distribution are exactly the same, so should be only an oblique line in the figure.

In the figure 3, it is the lateral acceleration residual normality examination, we can see a scatter of residual cumulative probability graph are near the line, which shows that the regression model residual error basically accord with normal distribution.

Through the inspection, the regression model of the lateral acceleration is statistically significant, which can be used for analysis and prediction.

Taking significance test、coefficient of goodness of fit 、test inspection and normality of residuals separately for the sensitive parameters regression model of the inside of the front wheel, the inside of the rear wheel, the outside front wheel and the outside rear wheel . Test show that the established the regression model of the sensitive parameters is reasonable and effective.

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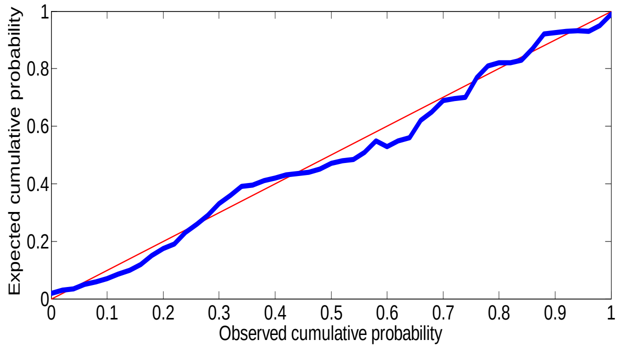

Fig.3. lateral acceleration of the regression residual probability map

IV. Prediction of High-Speed Motion Response of Puncture Conditions

Using the established sensitive parameters of multivariate linear regression model predict flat tire after instantaneous motion response of the vehicle when the cars are driven in turn. Set test conditions for normal driving speed of 120km/h, the tire pressure is 210 kPa, flat tire when the speed is 120km/h, tire pressure reduce to 0 kPa. In table 5, the most sensitive stability of the vehicle compare with second sensitive parameter values between the normal tire pressure and after different locations tire wheels.

Table 5: All sensitive parameters analysis

parameters	tire wheel	normal	tire blow-out	percentage change
acceleration/($m\cdot s^{-2}$)	inside front	3.248	7.868	142%
	inside rear	3.298	7.288	121%
Yaw rate/($^{o}\cdot s^{-1}$)	inside front	4.889	10.139	107%
	inside rear	4.921	9.751	98%
	outside front	3.353	0.623	-81%
	outside rear	3.543	0.603	-83%
Angle/(°)	outside front	-1.780	-3.460	94%
	outside rear	-1.490	-3.590	141%

As is shown in Table 5,

① The lateral acceleration of the inside wheel after high speed puncture is 7.868 $m\cdot s^{-2}$ and 7.288 $m\cdot s^{-2}$,it is exceeded approximately 2 times than the normal driving. It can be inferred car swings intensifies when cornering with the inside wheel puncture occurs. There is increasing tendency to yaw steering, and it can easily lead to slip and drift.

② The inclination of the outside wheel after high speed puncture is -3.460^{o} and -3.590^{o}, it is exceeded approximately 2 times than the normal driving. Yaw velocity is 0.623 $^{o}\cdot s^{-1}$ and 0.603 $^{o}\cdot s^{-1}$,it is much smaller than the normal driving. It is close to the normal straight line when driving. It can be inferred cars will be off track when cornering with the inside wheel puncture occurs and can be easily lead to the rollover.

③ The inside of the front tire blowout, side acceleration increases by 142%,yaw velocity increases by 107%， When the inside rear tire blow-out, Side acceleration increases by 121%， yaw velocity increases by 98% ; The outside of the front tire blow-out, Yaw velocity fell 81 %.The roll angle increases 94%, when The outside rear tire blowouts, Yaw velocity fell by 83%,the roll angle increases by 141%.It can be seen, the inner and the outer rear wheel puncture happened is more dangerous situation, especially the inside front wheel puncture occurred at greater risk.

V. Conclusion

Based on the established sensitive parameters regression model, this paper forecasts the speed of high speed tire condition 120 km/h. The results showed that when the inner wheel has a flat tire, the lateral acceleration is still the most sensitive to changes in the parameters, the lateral acceleration of the inner front wheel can reach to 7.868 $m\cdot s^{-2}$, the lateral acceleration of the inner rear wheel can reach to 7.288 $m\cdot s^{-2}$, when the outer wheel has a flat tire roll angle is still the most sensitive to changes in the parameters, The roll angle of the outer front wheel can reach to 3.460°, the roll angle of the outer rear wheel can reach to 3.590°;the inner wheel flat tire make vehicles swing intensifies, which can increase yaw trend and can lead to spin and drift easily; the outer wheel flat tire will make the car deviate from the straight running track and can lead to rollover easily. In addition, further research found that the inner front flat tire and the outer rear flat tire is a more dangerous working conditions, especially the inner front flat tire is a greater risk. These conclusions is significant for flat tire stability control strategy research.

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