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Study on the Matching of Toe-in and Camber of the Double-Front-Axle Steering Automobile

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Study on the Matching of Toe-in and Camber of the Double-Front-Axle Steering Automobile

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Abstract. Toe-in and camber of the wheel are important driving performance parameters in the four-wheel positioning parameters of automobile. In this paper, the mathematical geometrical models of toe-in and camber of the first and second bridges of the double-front-axle automobile are established, concluded that the relationship of toe-in and camber between the first bridge and the second bridge. At the same time, based on the side slip mechanism of the tire, the reasonable matching formula for toe-in and camber of the double-front-axle are concluded. Finally, according to the dynamic model established in the Adams/Car, the matching values of toe-in and camber are simulated and verified. The experimental results show that the matching value is reasonable and effective, for the matching of toe-in and camber of double-front-axle steering wheel has a certain guiding role.

1. Introduction

Toe-in and camber of wheels are important front-wheel positioning parameters to the front wheel of automobile. Reasonable matching between toe-in and camber of wheels can reduce the wear condition of tire [9] and improve the handling stability of automobile. At present, there is a lot of literature [1-5] about the matching of toe-in and camber of single-axle steering automobile. Considering the aspect of mechanics in the literature [1, 2], the matching relationship between toe-in and camber is derived by cancelling out the force which generated by toe-in and camber of the tire. In the literature [3, 5], according to the motion trail of wheels, the matching relationship between toe-in and camber can also be deduced. But none of these literatures mentioned above refer to the matching of toe-in and camber of steering wheels in the double-front-axle automobile. In addition, there are few studies on toe-in and camber of the double-front-axle steering wheels at present.

In order to achieve this goal, first, the geometrical relationship between toe-in and camber of the first and second bridges can be derived by establishing the mathematical geometry of toe-in and camber of the double-front-axle steering wheels. Then, the matching relationship between toe-in and camber of double-front-axle steering wheels can also be deduced according to the side slip mechanism of the tire. Finally, the result of simulation experiments can be verified by the dynamic model.

2. Matching study of toe-in and camber of double-front-axle

2.1. The relationship of camber between first and second bridges of double-front-axle

On account of the camber angle of wheels, wheels of automobile will always have the tendency to roll outward during driving. Taking the first bridge camber as an example, the geometry model of rolling wheel camber can be established, as shown in figure 1 [3, 5]:

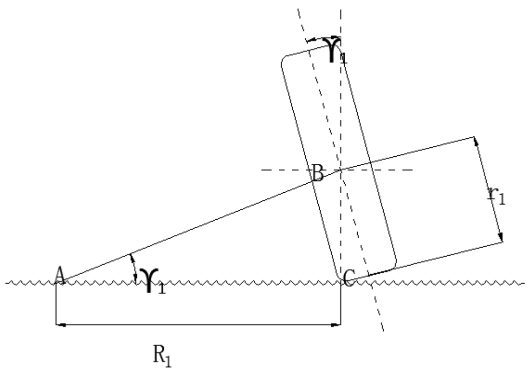

Figure 1. Rolling schematic diagram of the first-bridge camber.

Where, R_1 means the outer rolling radius of the first bridge which are caused by the camber of the tire, r_1 represents the rolling radius under load, and γ_1 indicates the camber of the first bridge of steering wheels.

Therefore, according to the geometric relationship graph of the first bridge, we can get the following relation:

In △ABC, $R_1 = r_1 / \sin\gamma_1$. Due to the small camber angle, $\sin\gamma 1 \approx \gamma 1$, the rolling radius of the first bridge can be expressed as

$$R_1 = r_1 / \gamma_1 \tag{1}$$

In the same way, the rolling radius of the second bridge can be obtained:

$$R_2 = r_2 / \gamma_2 \tag{2}$$

Where $$r_1 = D/2 - G_1/6K_Z \tag{3}$$

$$r_2 = D/2 - G_2/6K_Z \quad [6] \tag{4}$$

D is typical of the diameter of wheels under no load, G_1 and G_2 represent the vertical load above the first and second bridges, and K_Z is the radial stiffness of the tire.

During steering process of the automobile, the camber angle will changes with the change of the wheel angle, but in the process of this change, we can get such a regularity, that is, the turning radius of each steering wheels (ρ_1, ρ_2) and the rolling cone radius caused by the camber of wheels (R_1, R_2) are as close as possible.

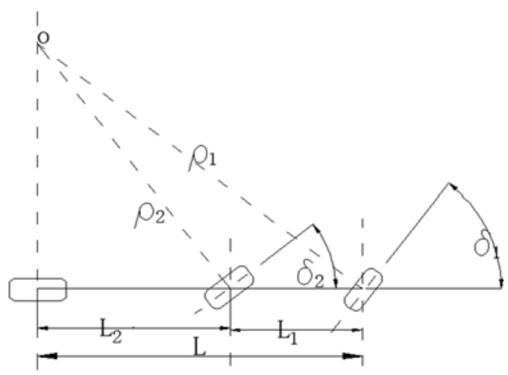

Figure 2. Steering schematic diagram of the double-front-axle.

Where δ_1, δ_2 are the angles of the first and second bridges of steering wheels respectively, ρ_1, ρ_2 indicate the turning radius of the first and second bridges of steering wheels. According to the geometric model of figure 2, we can obtain the following geometric relationship: $\rho_1 = L / \sin\delta_1$, $\rho_2 = L_2 / \sin\delta_2$;

When the conditions $R_1 = \rho_1$, $R_2 = \rho_2$ have been met, the minimum wear of the tire can be guaranteed, we can get the following relationship at present:

$$\gamma_1 = r_1 \sin\delta_1 / L \tag{5}$$

$$\gamma_2 = r_2 \sin\delta_2 / L_2 \tag{6}$$

When steering angles of automobile is small, that is, the condition $\cos\delta_1 / \cos\delta_2 \approx \delta_1 / \delta_2$ can be satisfied. So it can be approximated that the automobile is in straight-line driving state, and the camber angles of the first and second bridges are both initial camber angles.

According to (5) and (6), the relationship between the first bridge and the second bridge of camber can be obtained:

$$\begin{aligned} \gamma_1 / \gamma_2 &= (L_2 / L) \times (\sin\delta_1 / \sin\delta_2) \times (r_1 / r_2) \\ &= (L_2 / L) \times (\tan\delta_1 / \tan\delta_2) \times (\cos\delta_1 / \cos\delta_2) \times (r_1 / r_2) \\ &= (L_2 / L) \times (L / L_2) \times (\cos\delta_1 / \cos\delta_2) \times (r_1 / r_2) \\ &= (\cos\delta_1 / \cos\delta_2) \times (r_1 / r_2) \\ &\approx (r_1 / r_2) \end{aligned} \tag{7}$$

2.2. The relationship of toe-in between first and second bridges of double-front-axle

Compared with the single-bridge automobile, the double-front-axle automobile has two more steering wheels, so the rolling radius arose from toe-in of the double-front-axle automobile is slightly different from that of the single-bridge automobile. So it can be approximated that the toe-in angle is equivalent to a small corner of the tire. In order to ensure the tire wears minimally during the driving process, the steering wheel should roll around a same point [10].

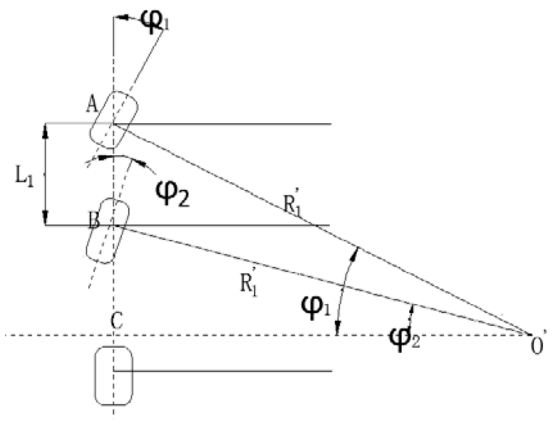

Figure 3. Toe-in rolling schematic diagram of the double-front-axle

Where φ_1, φ_2 indicate toe-in angle of the first and second bridges, R'_1, R'_2 represent the rolling radius of the first and second bridges which caused by the toe-in. φ_1, φ_2 are very small among them, so it can be approximated that $\sin\varphi_1 \approx \varphi_1, \sin\varphi_2 \approx \varphi_2$.

According to the aforementioned toe-in rolling schematic diagram shown in figure 3:

In △OBC:

$$R'_1 \times \sin\varphi_1 \approx R'_1 \times \varphi_1 = L = AC \tag{8}$$

In △OAC:

$$R'_2 \times \sin\varphi_2 \approx R'_2 \times \varphi_2 = L_2 \tag{9}$$

We can conclude that:

$$AC = L_1 + BC \tag{10}$$

by observing the geometric relationship of the graph above.

According to (8), (9), (10) the relationship of toe-in of double-front-axle can be obtained as follow:

$$R'_1 \times \varphi_1 = R'_2 \times \varphi_2 + L_1 \tag{11}$$

In the above-mentioned formula, φ_1, φ_2 can be expressed as

$$\varphi_1 = T_1 / \mathrm{d} \tag{12}$$

$$\varphi_2 = T_2 / \mathrm{d} \tag{13}$$

Where T_1, T_2 represent toe-in of the first and second bridges of steering wheels respectively, and d is the diameter of hub.

In the relation (11), the rolling radius of toe-in of the first and second bridges varies with the change of the toe-in angle of the first and second bridges of steering wheels. The toe-in value of the first and second bridges will be determined there-in-after by matching toe-in with that camber of the first and second bridges.

2.3. Study on the matching relationship between toe-in and camber of the first and second bridges of double-front-axle

In the following, based on the side slip mechanism of the tire, considered the minimum slip of the tire in the double-front-axle automobile during driving, with a view to the parameters of mechanism, combined with the relationship of toe-in and camber of the first and second bridges of double-front-axle above. The reasonable matching formula of toe-in and camber of the first and second bridges of double-front-axle has been determined.

Considering the toe-in and camber synthetically, we can take the first-bridge steering wheels of double-front-axle automobile as an example, the motion curve [3, 5] of tire shown in the following figure is established:

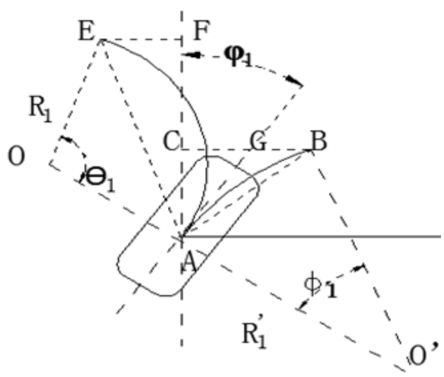

Figure 4. Rolling schematic diagram of the first-bridge camber and toe-in.

In figure 4, $\widehat{AB}$and $\widehat{AE}$indicate the grounding mark caused by toe-in and camber of wheels during Δt (time) respectively. φ_1 represents the toe-in angle of the first-bridge steering wheels, ϕ_1, θ_1 respectively express the rolling angle of wheel during Δt(time) under the action of toe-in and camber. R , R'_1 represent the rolling radius of toe-in and camber respectively.

In order to ensure the minimum side slip of tires during driving, EF=BC must be guaranteed.

In △AEF:

$$EF = AE \times \sin(\frac{\theta}{2} - \varphi_1),$$

In △ABC:

$$BC = AB \times \sin(\frac{\phi}{2} + \varphi_1);$$

Available from EF=BC,

$$\theta_1 = \phi_1 + 4\varphi_1 \tag{14}$$

can be obtained.

At the same time, when the rolling radius is large enough, the following formulas are satisfied:

$$\widehat{AB} = AB = \widehat{AE} = AE = l1,$$

where l_1 indicates the actual grounding mark of the first bridge [7].

$$\text{Also, } \widehat{AB} = R_1' \times \phi 1 = l1 \tag{15}$$

$$\widehat{AE} = R1 \times \theta 1 = l1 \tag{16}$$

From the formulas (1), (3), (12), (14), (15), (16), the matching formula of toe-in and camber of the first bridge can be obtained:

$$T_1 = \frac{12 K_z L l_1 \gamma_1 d}{(4L + l_1)(3DK_z - G_1)}$$

In the same way, we can also get the matching formula of the second bridge:

$$T_2 = \frac{12 K_z L_2 l_2 \gamma_2 d}{(4L_2 + l_2)(3DK_z - G_2)}$$

Combined with the relationship between toe-in and camber of the first and second bridges of the double-front-axle, we can get the matching relationship between the toe-in and the camber of the double-front-axle:

$$T_1 = \frac{12 K_z L l_1 \gamma_1 d}{(4L + l_1)(3DK_z - G_1)},$$

$$T_2 = \frac{12 K_z L_2 l_2 \gamma_2 d}{(4L_2 + l_2)(3DK_z - G_2)},$$

$$\gamma 1 / \gamma 2 \approx \mathrm{r}1 / r2$$

Where, l_1 , l_2 represent the grounding mark of the first and second bridges of the tires respectively,

$$l_1 = 2\sqrt{(\mathrm{D} - \Delta_1)\Delta_1},$$

$$l_2 = 2\sqrt{(\mathrm{D} - \Delta_2)\Delta_2},$$

$$\Delta_1 = 19.1\,\mathrm{CK}(0.5G_1)^{0.85} / B^{0.7} D^{0.45} P^{0.6},$$

$$\Delta_2 = 19.1CK(0.5G_2)^{0.85} / B^{0.7} D^{0.45} P^{0.6}.$$

In the formula above, C and K are coefficients, K=0.0015B+0.42, B is the section width of tire, G1, G2 are the loads on the first and second bridges respectively, D represents the diameter of tire, and P is the tire pressure.

3. Practical calculation and simulated analysis

3.1. Practical calculation of toe-in value and camber angle of the steering wheel of the first and second bridges of the double-front-axle prototype vehicle

In order to verify the correctness of the matching formula of toe-in and camber of the double-front-axle mentioned above, the JAC GEFA Y4AP0 double-front-axle heavy truck will be used as the prototype vehicle. According to the data parameters of the prototype vehicle, the toe-in value and the camber angle of the first and second bridges of the double-front-axle will be calculated.

Table 1. Data parameters of the double-front-bridge prototype vehicle.

d/mm	D/mm	G_1/N	G_2/N	B/mm	K_Z/(N/mm)
571.5	1008	37500	19950	300	117.78
L/mm	L_1/mm	L_2/mm	P/(100ka)	C	
4300	1900	2400	7	1.5	

According to the aforementioned vehicle data parameters, combining with the matching formulas of toe-in and camber of the double-front-axle. If a camber angle of the first bridge of a wheel can be given, the toe-in value of the first bridge, the camber angle and toe-in value of the second bridge can all be calculated by matching formula mentioned above.

In the general case, the camber angle of wheels are mostly about 1 °, according to the actual situation of this automobile, the camber angle of the first bridge can be given γ_1=1°, then combining with the parameters and matching formulas of double-front-axle automobile, the toe-in value of the first bridge of wheels are T1=2.47mm, and the toe-in angle is φ_1=0.104°.Similarly,the camber angle of the second bridge of wheels are γ_2=1.05°, the toe-in value of the second bridge of wheels are T2=1.42mm,and the toe-in angle is φ_2=0.059 °.

3.2. Simulation verification of vehicle dynamics model based on Adams/car

According to the vehicle dynamics model established in Adams/car, we conduct the relevant simulation experiments of straight-line driving and steering driving of whole vehicle. In order to verify the rationality of the matching formulas mentioned above, we should compare with the side slip of the four-steering wheels of the first and second bridges, before and after modifying toe-in angles (values) and camber angle of the first and second bridges of double-front-axle.

Simulation of straight-line driving: Straight-line Maintain driving simulation with the dynamic model in Adams/Car are performed, with the duration of 15s, keeping the steering wheel for free.

The following simulation contrast curves were made by the above-mentioned straight-line driving simulation which was carried out separately on the original double-front-axle dynamic model and that after modifying toe-in and camber.

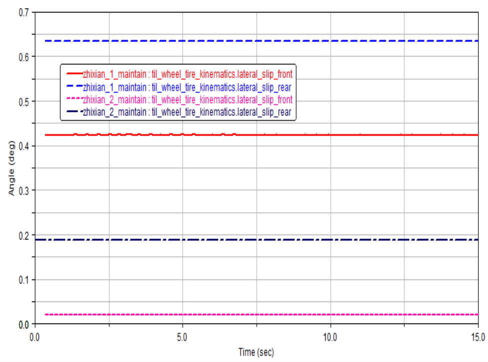

Figure 5. Side-slip comparison of the first and second bridges of tires on the left side of the straight-line driving

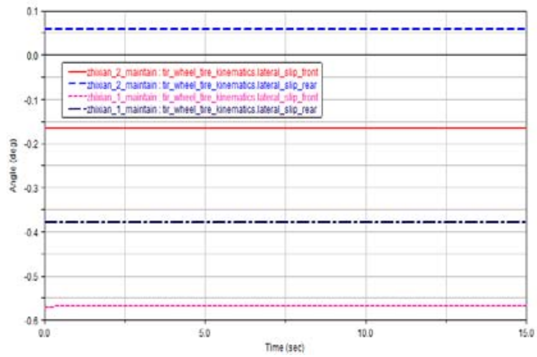

Figure 6. Side-slip comparison of the first and second bridges of tires on the right side of straight-line driving

We can get some information from Figure 5 that the left side slip angle of the first bridge is reduced from 0.43° to about 0.02°,and the left side slip angle of the second bridge is reduced from 0.63° to about 0.18°.Again,as we can see from Figure 6,the right side slip angle of the first bridge is changed from -0.58° to about -0.16°, and the right side slip angle of the second bridge is changed from -0.38° to about 0.06°.Comparing with two simulation lines above, it can be found that the side slip of the tire is obviously improved after modifying the camber and toe-in angle of the first and second bridges of double-front-axle steering wheels.

Simulation of steering driving: Performing the dynamic model of Cornering steering Release driving simulation in Adams/Car, the lateral acceleration and the longitudinal driving speed are set to 0.2g and 28km/m respectively.

The following simulation contrast curves were made by the above-mentioned steering driving simulation which was carried out separately on the original double-front-axle dynamic model and that after modifying the toe-in and camber.

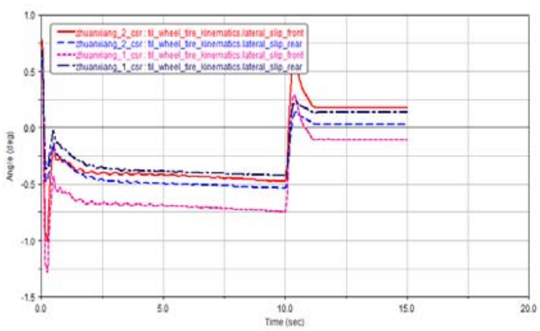

Figure 7. Side-slip comparison of the first and second bridges of tires on the left side of steering driving.

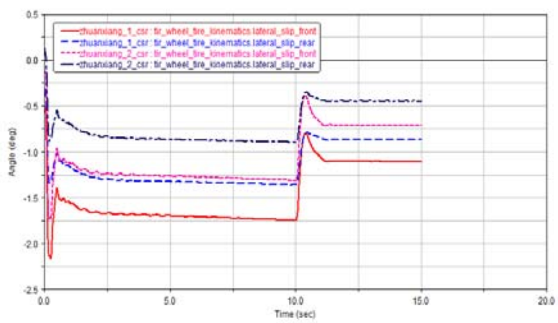

Figure 8. Side-slip comparison of the first and second bridges of tires on the right side of steering driving.

The conclusion about side-slip angle is obtained in figure 7: after modifying toe-in and camber of double-front-axle model, the left side-slip angle curve of the first and second bridges of steering wheels tends to be about 0° compared with the original model. Similar conclusions can also be drawn in Figure 8.

4.Conclusions

• Considering the minimum wear of tires, the geometric relationship between toe-in and camber of the first and second bridges of the double-front-axle is established. At the same time, based on the side slip mechanism of tires, the matching formula of camber and toe-in of the double-front-axle is derived. In addition, the simulation experiment is verified by the dynamic model Y4AP0, which proves the rationality of the matching formula.

• The relationship between the first and second bridges of the double-front-axle was clarified, and exploring the relationship between the first and second bridges of the double-front-axle.

• The matching formula obtained in this paper has a certain theoretical guiding effect on the matching of the four-wheel positioning parameters of steering wheels of the double-front-axle automobile.

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