**Summary table of the resistant torque acting on the EPS steering system for wheel alignments**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Camber angle | Caster angle | Kingpin angle | Equation for the resistant torque | Illustration |
| Longitudinal forces |  | X | X | ]  While:  *“DESIGN OF STEERING WHEEL FORCE FEEDBACK SYSTEM WITH FOCUS ON LANE KEEPING ASSISTANCE APPLIED IN DRIVING SIMULATOR”* |  |
| Lateral forces | X | X | X | While: , and trail  *“DESIGN OF STEERING WHEEL FORCE FEEDBACK SYSTEM WITH FOCUS ON LANE KEEPING ASSISTANCE APPLIED IN DRIVING SIMULATOR”* |  |
| Normal force |  | X | X | *“DESIGN OF STEERING WHEEL FORCE FEEDBACK SYSTEM WITH FOCUS ON LANE KEEPING ASSISTANCE APPLIED IN DRIVING SIMULATOR”* |  |

*Caster Angle*

**]**

**The longitudinal forces ()**

*Kingpin Inclination Angle*

*Caster Angle*

**The resistant torque**

**The resistant torque**

*Kingpin Inclination Angle*

**The lateral forces ()**

**The resistant torque**

*Camber Angle*

*Caster Angle*

**The vertical force ()**

**The resistant torque**

*Kingpin Inclination Angle*

* **Note:** and lateral force will be calculated by **linear tire model.**
* **The resistant force caused by longitudinal forces:**

**]**

Diagram

Description automatically generated

The moment arm:   
**d =**

The resistance torque by FX:

*Scrub radius and tire radius*

Lateral force:

*Cornering Stiffness*

**The total longitudinal force**:

*Friction coefficient*

Longitudnal force:

*Wheelbase l*

Normal force:

*Vehicle mass m*

Rolling resistance:

*Gravitational  
acceleration g*

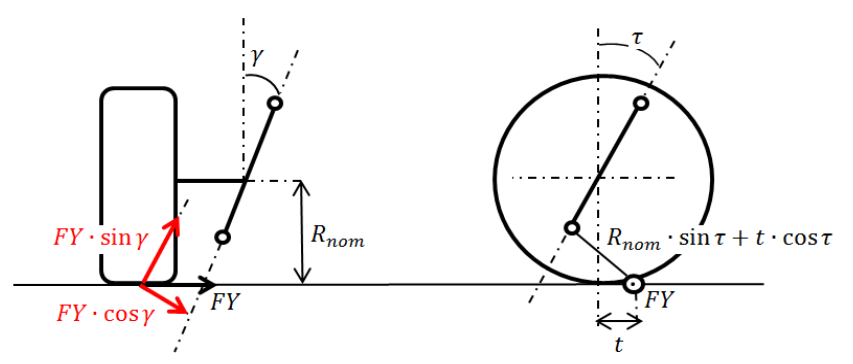
*Rolling resistance coefficient*

**Step 1:** Estimate the total longitudinal forces**:**

**Step 2:** Estimate the moment arm **d =**

While:

* **The resistant force caused by lateral forces:**



**B**

**A**

* **Calculation diagram**:

The moment arm:   
**d**

The resistance torque by FY:

*The total trail t and tire radius*

Lateral force:

*Cornering Stiffness*

**The total lateral force**:

*Friction coefficient*

Longitudnal force:

*Wheelbase l*

Normal force:

*Vehicle mass m*

Rolling resistance:

*Gravitational  
acceleration g*

*Rolling resistance coefficient*

**Step 1:** Estimate the total lateral forces**:**

**Step 2:** Estimate the moment arm:

* **The resistant force caused by normal forces:**

* **Calculation diagram**:

The resistance torque by FZ:

The moment arm:   
**d**

*The scrub radius and tire radius*

**The total lateral force**:

**)**

*Wheelbase l*

Normal force:

*Vehicle mass m*

*Gravitational  
acceleration g*

**Step 1:** Estimate the total normal forces**: )**

While: S

**Step 2:** Estimate the moment arm:

* **How to find the lateral force, normal force, longitudinal force and rolling resistance force?**
* **Longitudinal force:** It is a force acting along the x-axis. The resultant longitudinal force > 0 if the car is accelerating, and < 0 if the car is braking. Longitudinal force is also called forward force.

**(Jazar, R. N. (2013). Vehicle dynamics: Theory and application. Springer Science & Business Media)**

* **Rolling resistance:**

While:

* **Lateral force:**

**(***Jazar, R. N. (2013). Vehicle dynamics: Theory and application. Springer Science & Business Media***)**

Camber angle is the tilting angle of tire about the longitudinal x-axis. Camber angle generates a lateral force Fy called camber trust or camber force. Camber angle is assumed positive > 0, when it is in the positive direction of the x-axis, measured from the z-axis to th tire. A positive camber angle generates a camber force along the -y-axis. The camber force is proportional to γ at low camber angles, and depends directly on the wheel load Fz. Therefore,

**(***Jazar, R. N. (2013). Vehicle dynamics: Theory and application. Springer Science & Business Media***)**

In presence of both, camber γ and sideslip α, the overall lateral force Fy on a tire is a superposition of the corner force and camber trust

**+**

**(***Jazar, R. N. (2013). Vehicle dynamics: Theory and application. Springer Science & Business Media***)**

**\***However, Camber angle is typically set to achieve near-zero camber angles for the deflections encountered under the main dynamic load condition. Normally, the selection of camber and toe angle is dominated by attempts to reduce front tire wear rather than to improve the handling.

Besides, we can take the front sideslip angle(because model in this proect only consider at front steering system) and vehicle sideslip angle by using below equation:

*(Du, P., Su, H., & Tang, G. (2018). Active return-to-Center control based on torque and angle sensors for electric power steering systems.* [*https://doi.org/10.20944/preprints201803.0098.v1*](https://doi.org/10.20944/preprints201803.0098.v1)*)*

front wheel steer angle

is the angle between the X-axis and the velocity at the mid point of the front shaft.

sideslip angle at the center of gravity of the vehicle.

is the distance from front tire to the vehicle’s center of mass.

yaw rate of the vehicle’s center of mass.

longitudinal velocity of the vehicle at center of mass.

*(Bhardwaj, A., Slavin, D., Walsh, J., Freudenberg, J., & Gillespie, R. B. (2021). Estimation and decomposition of rack force for driving on uneven roads. Control Engineering Practice, 114, 104876. https://doi.org/10.1016/j.conengprac.2021.104876)*

* In the resistant moment caused by lateral force, we use the linear model and the magnitude of this torque will be estimated by the equation mentioned in **The Summary Table** and the trail equal the sum of **the mechanical trail and pneumatic trail.**
* The mechanical trail : is the constant distance which is determined by the caster angle of the vehicle and radius of the tire. This parameter is different among vehicles.
* The pneumatic trail for the LT Model is given by the expression:

*(Bhardwaj, A., Slavin, D., Walsh, J., Freudenberg, J., & Gillespie, R. B. (2021). Estimation and decomposition of rack force for driving on uneven roads.*Control Engineering Practice*,*114*, 104876.*[*https://doi.org/10.1016/j.conengprac.2021.104876*](https://doi.org/10.1016/j.conengprac.2021.104876)*)*

While: is the pneumatic trail at zero slip angle = 0.03m

front side slip angle

**Model Parameters**

|  |  |  |
| --- | --- | --- |
| **Symbols** | **Value** | **Name** |
|  | 0.03 [m] | Pneumatic trail at zero slip angle |
| g | 9.81 [m/] | Gravity of earth |
|  | ?? [rad] | Caster angle |
|  | 0.011 | Rolling resistance coefficient |
|  | ?? [rad] | Kingpin angle |
|  |  | Cornering stiffness of tire |
|  | 0.35-0.4 | Friction coefficient |
|  | ?? [m] | Nominal radius of tire |
|  | ?? [m] | Wheelbase |
|  | ?? [m] | Distance from the center of vehicle to rear axle |
|  | [rad] | Front side slip angle |
|  | [m] | Pneumatic trail |
|  | [m] | Mechanical trail |
|  | [m] | Total trail |
|  | [m] | Scrub radius |
|  | [rad] | Wheel steer angle |
|  | [N] | Longitudinal force |
|  | [N] | Lateral force |
|  | [N] | Rolling resistance force |
|  | [N] | Normal force |

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**A screenshot of a computer

Description automatically generated with low confidence**