Turning Safety Research of Concrete Mixer Truck Based on Lab VIEW

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***Abstract*--According to the analysis of concrete mixer truck's stability, a theoretical calculation method is come up with, which can calculate its safety speed when turning. In addition, the paper put forward building a program graph of the system that can compute real-time safe velocity and designing a corresponding front-panel diagram, based on the virtual instrument software environment of LabVIEW. And the system has safety alarm function for mixing truck driving, as well.**

Keywords: safety speed; real-time; LabVIEW; virtual instrument

I. INTRODUCTION

The increasing number of cars leads to a lot of traffic problem. Especially those accidents caused by concrete mixer truck rollover would bring huge property losses and serious security threats to life. The concrete mixer trucks are prone to roll because of its high center of gravity, poor stability, and complex road condition and so on. Among them, the high-speed turning condition is one of the most risk factors for rollover. In order to determine the concrete mixer truck's turning speed, the driver has to only depend on the familiarity with its performance. In view of this situation, it is necessary to propose a virtual instrument design which can reckon the real-time safe speed. And the safe speed is also able to be displayed on the panel, giving the driver a timely and scientific reference standard. If the driver didn't limit the velocity to the safe velocity, the system will alarm at the same time, prompting the driver to slow down, so as to ensure traffic safety.

II. CONCRETE MIXER TRUCK ROLLOVER MODEL

The vehicle rollover refers to the driving car rotates 90° or larger angle around its longitudinal axis, so that the body could contact the ground[1].The fundamental reason for rollover is that the car's lateral acceleration exceeds the limit which lateral load can compensate

Therefore, it's essential to establish an appropriate rollover kinetic model [2], in order to better study the concrete mixer truck's safety speed when turning. In this paper, the simplified linear three degrees of freedom vehicle model is established to analyze the critical speed for rollover. As shown in figure 1, the model includes the lateral movement along the y direction, the horizontal pendulum movement around the z axis and lateral movement around the x axis.

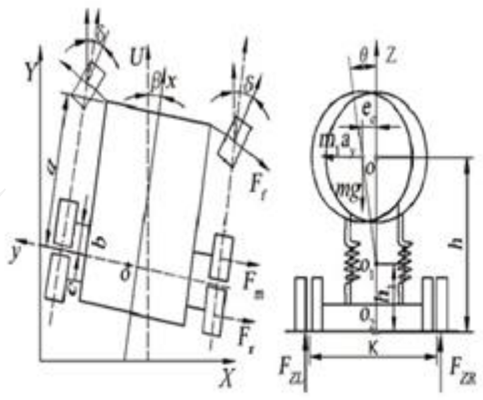


Figure 1. Concrete mixer truck rollover model.

The model can get the following dynamics equations, balance equation along the Y axis movement:

$$mV(\beta+\gamma)-m(h-h_1)\ddot{\theta}=-(2F_f\cos\delta+4F_m+4F_r) \quad (1)$$

balance equation around the z axis movement :

$$I_z\gamma=-2aF_f+4bF_m+4cF_\gamma \quad (2)$$

balance equations Around the x axis movement：

$$I_x\ddot{\theta}=m(h-h_1)V\left(\dot{\beta}+\gamma\right)+mgh\theta-k_\theta\theta-c\dot{\theta} \quad (3)$$

Among them：

$F_f=k_f$; $F_m=k_m\varepsilon_2$; $F_r=k_\gamma\varepsilon_3$;

$\varepsilon_1=\beta+\gamma\alpha/v-\delta-\xi_f\theta$; $\varepsilon_2=\beta-\gamma b/v-\xi_m\theta$;

$\varepsilon_3=\beta-\gamma c/v-\xi_\gamma\theta$

In the formulas: δ —the front wheel steering angle; β —the side-slip angle of center of mass for concrete mixing transporter; γ —yawing angular velocity;

θ—the body roll angle; α , b , c—the distance from the center of mass to the front axle, middle axle and the rear axle; F_f , F_w , F_r—the cornering force of the front wheel, middle wheel and the rear wheel; ε_1 , ε_2 , ε_3—the side-slip angle of the front wheel, middle wheel and the rear wheel; k_f , k_m , k_r—the cornering stiffness of the front wheel, middle wheel and the rear wheel; k_θ—stiffness of the suspension roll angle;

h—the distance from center of mass for the curb weight of agitation tank to the ground; h_1—the distance from roll center to the ground; I_Z—the yawing moment of inertia; I_x—the rotational inertia of the sprung mass around the x axis; K—wheel tread; ξ_f , ξ_m , ξ_r—influence coefficient of roll motion of the body; O_1—unsprung mass centre; O_2—the projection of unsprung mass centre

In order to better study the rollover stability of the concrete mixing transporter, the roll model ignores the deformation of tires and the variation of roll angles, but considering the changes of suspension. And LTR [3]—a rollover coefficient is introduced. LTR is the ratio of load difference between left tire and right tire to total load.

$$LTR = \frac{\left|F_{ZL} - F_{ZR}\right|}{F_{ZL} + F_{ZR}} \tag{4}$$

In the formula (4): F_{ZL} , F_{ZR}—left side, right side of the front and rear wheel of the total vertical load.

When LTR is equal to 0, the vertical load on both sides of tires is the same, and it shows that the mixer truck rollover will not occur at this moment; while LTR is equal to 1, the vertical load on one side of tires is zero, and it means this side of tires get off the ground, so the vehicle rollover may occur in this case. Due to the moment balance, the torque acting on O_2 is balance, thus, the following formula (5) can be obtained.

$$\frac{1}{2}KF_{ZL} - \frac{1}{2}KF_{ZR} - m_1 a_y h - m_1 g\left(h - h_1\right)\tan\theta = 0 \tag{5}$$

a_y is the centrifugal acceleration of circular motion.

$$a_y = \frac{V^2}{R} \tag{6}$$

As LTR is equal to 1, the mixer truck rollover will occur. And the following equation is able to be got by formula (5) and (6).

$$V_C = \sqrt{\frac{RmgK - 2Rm_1 g\left(h - h_1\right)\tan\theta}{2m_1 h}} \tag{7}$$

In the equation (7): m—the total mass of the concrete mixer truck; m_1—sprung mass; R—turning radius of the vehicle; V_c—the critical speed of rollover.

III. MAIN TITLE

A. *The determination of turning radius*

The distance from the steering center to the point of the outside steering wheel contacting with the ground is called turning radius.

In an ideal situation:

$$R = \frac{L}{\sin\beta} \tag{8}$$

Thus, it is not hard to draw the corresponding turning radius in the moment of the mixer's turning, as long as the outside steering wheel deflection angle is known. In fact, there is a certain relationship between both sides of the steering wheel deflection angle. As shown in the figure2:

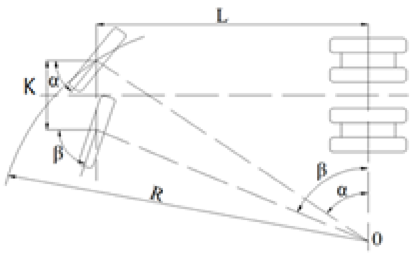


Figure 2. The ideal relationship between the deflection angles of the steering wheels on both sides

α—outside steering wheel deflection angle; β—inside steering wheel deflection angle.

And an angle sensor is fixed on the king pin of the mixer truck steering wheel on the right side, so that the value of α can be received at any time. Now, α is outside steering wheel deflection angle, however, when the mixer truck turns right, α is inside steering wheel deflection angle. As the car makes a turn, the inside and outside steering wheel angle satisfies Ackerman principle, namely:

$$\cot\alpha - \cot\beta = \frac{K}{L} \tag{9}$$

In the formula (9): α—outside steering wheel deflection angle; β—inside steering wheel deflection angle; L—wheelbase; K—wheel tread;

With the value of α received by the angle sensor and the calculation of Ackerman principle, the value of β is able to be computed, so as to calculate the corresponding turning radius.

Due to the characteristics of steering trapezoidal mechanism as well as the requirement of performance of vehicles, there will be a certain error between the actual angle and Ackerman angle. Moreover, different types of cars are slightly different. At present, because the turning speed of the car is not high, the actual angles of inside and outside conform to this principle [4], broadly. Article 4.1.15 of China's automobile industry standard QC/T667-2010, " experimental method and technical condition of concrete mixing transporter ” , specified: when concrete mixer truck drives with mixing, its maximum speed is not more than 50Km/h. So the speed is far lower than the highest speed in the turning condition and the requirements of the Ackerman theorem is apparently satisfied.

B. The determination of preliminary angle

The bend road refers to the center line in the state of the curve, and its size is measured by radius of the bend. Because many accidents happen on the corner, it is dangerous to get through the corner. When the car get into the corner for a short distance or α is greater than a certain value, the outside steering wheel deflection angle would be calculated at $\alpha+\Delta\alpha$. This will eliminate the error of the response lag and actuator, so that the truck mixer is able to be in a safety state in advance. And $\alpha+\Delta\alpha$ is the preliminary angle. As shown in the figure3:

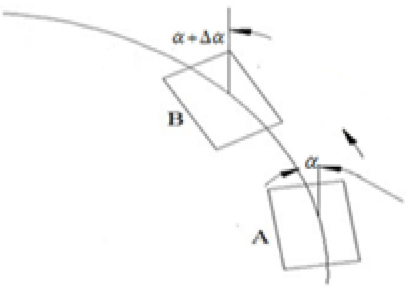


Figure 3. Schematic diagram of Preliminary angle

Based on the above theoretical analysis, the safe speed of B is less than the safe speed of A. When the concrete mixer truck drives at point A, the system begins to calculate the safe speed of point B. At this moment,the driving speed should be less than or equal to the safe speed of A. In this way, as the truck really reaches the rollover—prone point B, its rate has been already in the safe speed of B, thus, concrete mixer truck rollover in dangerous turning condition can be prevented effectively.

In general, the maximum angle of automobile steering wheel is about 40° [5], so, in this paper $\alpha_{\max}$ is regarded as 45°. When concrete mixer truck drives in the small curves and straight line, avoiding pedestrians or other vehicles, the steering wheel deflection angle is small, usually within 10°. In that condition, the speed of the mixer truck is within the stipulated, however, the safe speed of the car which drives in the large corner is the real focus. Therefore, the starting angle is considered as 10°. That is when the outside steering wheel deflection angle is bigger than 10°, the safe speed is calculated. Thus, 10° is temporarily regarded as the basis of theoretical research in this paper, according to the experience and comprehensive factors.

IV. THE ANALYSIS OF THE ENGINEERING EXAMPLE

Take a real full-loaded concrete mixer truck as the analysis of example to illustrate, and some related parameters are shown in table 1:

Table 1. Partial correlation parameters of mixer truck

Total mass(kg)	m	25000
Sprung mass(kg)	m_1	22000
Body roll angle	θ	15°
Mass centre to the ground distance(mm)	h	1806
Roll center to the ground distance(mm)	h_1	735
Wheelbase(mm)	L	4535
Wheel tread(mm)	K	2065

For the convenience of calculation, it is assumed that the value of α is 14° and $\Delta\alpha$ is 10°. When the concrete mixer truck turns left, α is the outside steering wheel deflection angle.

Turning radius: $R=\dfrac{L}{\alpha+\Delta\alpha}$ (10)

Put the relevant parameters into equation (10) and figure out that R is $11.15m$. While the concrete mixer truck turns right, α is the inside steering wheel deflection angle. According to $\cot\alpha-\cot\beta=\dfrac{K}{L}$, $\beta=12.6^\circ$, R is equal to $11.79m$ this time. As the full-loaded truck takes a left turn, V_L is $26.4km/h$ by the previous formula (7) and related data. And $V_R=27.9km/h$ can be computed similarly. Thus:

The critical speed of the rollover of left turning: $V_L=26.4km/h$

The critical speed of the rollover of right turning: $V_R=27.9km/h$

But now, there is still no specific provision about the value of the safety speed. It is suggested that V_S, safe velocity, should be looked upon as $76\% V_C$, according to the golden section method.

Namely: $V_S = 76\% V_C$

In conclusion:

The full-loaded truck's safe speed of left turning: $V_{SL} = 20.1km/h$

The full-loaded truck's safe speed of right turning: $V_{RL} = 20.6km/h$

Based on the above theoretical calculation and analysis of a real concrete mixer truck, a virtual instrument is designed, under the Labview software environment. The virtual instrument can compute the real-time safe speed in the process of truck's turning. And this virtual instrument also includes design of the front panel and construction of the program diagram. The front panel comprises setting-parameter button, control button, displaying-data button and so on. The structure of program diagram needs thoughtful calculation process and logical relationship, and it verifies its correctness through the form of data stream. If a little mistake takes place in the program, the data stream would be stopped, and the whole process will not be able to run, so the data won't be displayed on the front panel.

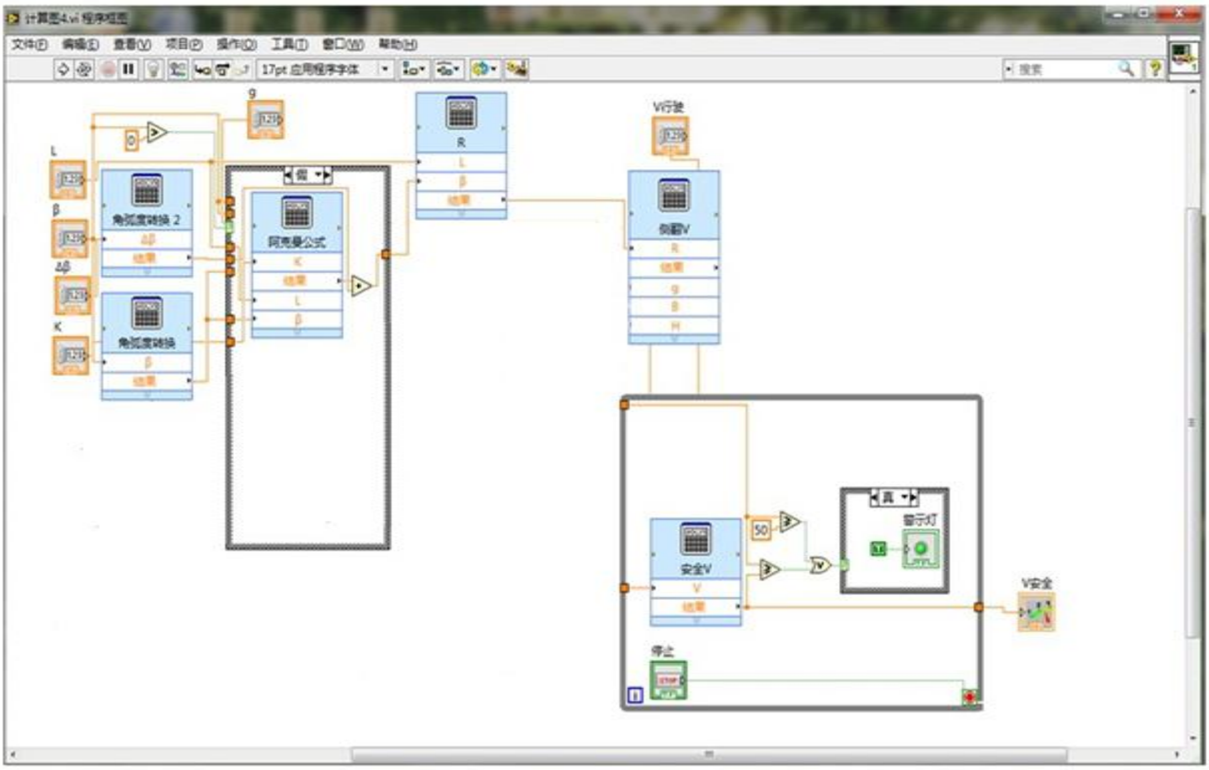
In the display interface of the virtual instrument, parameters can be set based on different types of concrete mixer trucks. The following diagram is the front panel of the full-loaded truck's right turning.

Figure 4. Front-panel diagram of right turn truck with full load

This moment, the driving speed of $20km/h$ is less than the safe speed of $20.6km/h$, so the car is in the safety condition, and the indicator doesn't alarm, appearing as dark

The following figure 5 is the corresponding program diagram of right turn truck with full load.

Figure 5. Program diagram of right turn truck with full load



V. CONCLUSION

1. According to the analysis of full-loaded concrete mixer truck's roll stability, a method is summed up to calculate the safe speed in its turning condition.

2. On the basis of an engineering example's analysis in LabVIEW software development environment, the theoretical calculation of safe speed and the warning system are designed.

3. The virtual instrument can completely satisfy various computational requirements of the theoretical analysis, in accord with the results of theoretical calculation. With angle sensor, speed sensor, and weighing sensor, the instrument can intelligently display the real-time safe speed of the car in cornering, and determine whether the vehicle is in the safe speed condition. Thus, we're able to ensure the concrete mixer truck's driving safety when turning through the virtual instrument.

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