Study on Steering Ability of Articulated Vehicles under Complex Road Conditions

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Abstract—Based on the calculations of articulated vehicle's steering ability on flat road surface, taking an articulated vehicle as example, the calculating formulas of steering ability is discussed with the variational swinging angle of articulated vehicle. Through the simulations in Matlab, the paper analyzes the swinging angle influencing to articulated vehicles's steering ability. At last, based on the conclusion, the paper gives the optimized project of articulated steering mechanism under complex road conditions.

Keywords-steering ability; swinging angle; simulation; optimization

1. Introduction

Articulated Vehicle includes two separate segments that are connected by a vertical axis articulation joint and a pendular ring. Because they are mobile, flexible, versatile, economic, they are used widely in the forestry, construction, agriculture, and mining industries. Structurally, the articulation joint allows the front frame turning at an angle relative to the rear frame in the horizontal plane to achieve the steering function. The pendular ring allows the rear frame turning relative to the front frame in the vertical plane, so that they can adapt to the complex road conditions. On the uneven roads, the mechanism of the pendular ring can ensure that all wheels contacting with the ground to maintain vehicle stability and traveling capability[1].

Complex road conditions and its own specific structure lead to more trouble in studying performance of steering mechanism. In the past, the studies of articulated steering system are mostly based on the flat road conditions, and most of them focus on the calculation of steering resistance moment and hydraulic cylinder working pressure. In fact, the working condition of articulated vehicle are generally extremely poor, so the research of articulated steering system under complex traffic conditions becomes more meaningful. This paper develops the mathematical model to calculate their inherence steering ability under complex road conditions through an example. Using Matlab and other computer-aided software, variational swinging angle influencing to articulated steering ability is studied.

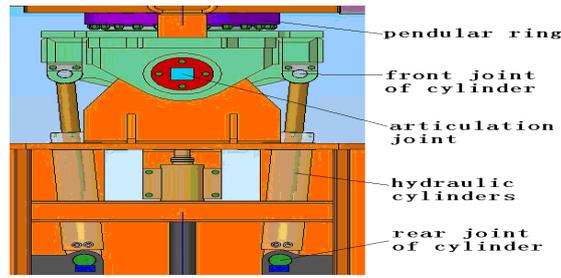[+] Corresponding author.
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Fig.1. Articulated steering mechanism

2. The Establishment of Mathematical Model

In this paper, an articulated vehicle steering system is taken as an example for the study. The steering system, shown in figure 1, accomplishes steering in the horizontal plane through the telescopic steering cylinder. On the uneven roads, the pendular ring can improve the stability and traveling capability of vehicle. Selecting the swing angle in design is a key issue. If the swing angle is too small, we can't gain the desired effect. If the swing angle is too large, vehicles would easily topple. The swing angle also has an impact on steering ability. But there's no a theoretical basis for us to select the swing angle in design. Usually, most of the swing angles of articulated vehicles are set at 12 °, 15 ° or 20 ° based on the design experience[2].

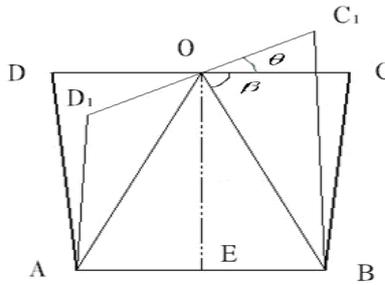Figure 2 is the schematic diagram of steering mechanism in the horizontal plane while the swing angle is zero.

Fig.2. Draft of steering mechanism in the horizontal plane (α =0)

where A, B and C, D are rear and front joints of hydraulic steering cylinder; O is center of articulation joint; θ is steering angle; C and D will be moved to C_1 and D_1 after steering angle becomes θ from 0.

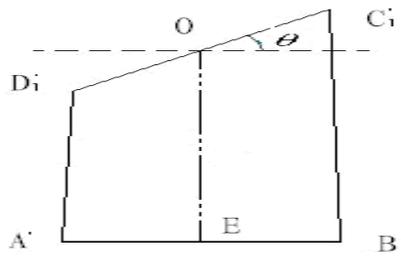Figure 3 is the projection draft of steering mechanism in the horizontal plane while the swing angle is α .

Fig.3. Projection draft of steering mechanism in the horizontal plane ($\alpha \neq 0$)

where $A_1^{'}, B_1^{'}, C_1^{'}, D_1^{'}$ are projection points of A_1, B_1, C_1, D_1 in the horizontal plan while the front frame turns at a angle of θ_1 relative to the rear frame respectively.

For Figure 2:

$$AD_1 = \sqrt{\left(OE - \frac{CD\sin\theta}{2}\right)^2 + \left(\frac{CD\cos\theta}{2} - \frac{AB}{2}\right)^2}$$

$$BC_1 = \sqrt{\left(OE + \frac{CD\sin\theta}{2}\right)^2 + \left(\frac{CD\cos\theta}{2} - \frac{AB}{2}\right)^2}$$

$$tg\beta = \frac{2OE}{AB}$$

The arm of force for point '0' of right-hand steering cylinder is

$$H_1 = \frac{\sqrt{OE^2+\left(\frac{AB}{2}\right)^2}\times\frac{CD}{2}\times\sin(\theta+\beta)}{\sqrt{\left(OE+\frac{CD\sin\theta}{2}\right)^2+\left(\frac{AB}{2}-\frac{CD\cos\theta}{2}\right)^2}}$$

The arm of force for point '0' of left-hand steering cylinder is

$$H_2 = \frac{\sqrt{OE^2+\left(\frac{AB}{2}\right)^2}\times\frac{CD}{2}\times\sin(\varphi-\theta)}{\sqrt{\left(OE-\frac{CD\sin\theta}{2}\right)^2+\left(\frac{AB}{2}-\frac{CD\cos\theta}{2}\right)^2}}$$

Based on the conclusions of above, we can gained the following equations for the condition of Figure 3.

$$W = \int_0^\theta Md\theta \tag{1}$$

$$M = \pi P\left[D^2 H_1' + \left(D^2 - d^2\right)H_2'\right]/4 \tag{2}$$

The arm of force for point '0' of right-hand steering cylinder is

$$H_1' = \frac{\sqrt{OE^2+\left(\frac{A'B'}{2}\right)^2}\times\frac{C_1'D_1'}{2}\times\sin(\theta+\beta)}{\sqrt{\left(OE+\frac{C_1'D_1'\sin\theta}{2}\right)^2+\left(\frac{A'B'}{2}-\frac{C_1'D_1'\cos\theta}{2}\right)^2}}$$

The arm of force for point '0' of left-hand steering cylinder is

$$H_2' = \frac{\sqrt{OE^2+\left(\frac{A'B'}{2}\right)^2}\times\frac{C_1'D_1'}{2}\times\sin(\beta-\theta)}{\sqrt{\left(OE-\frac{C_1'D_1'\sin\theta}{2}\right)^2+\left(\frac{A'B'}{2}-\frac{C_1'D_1'\cos\theta}{2}\right)^2}}$$

$$AB\cos\alpha = A'B'$$

$$C_1D_1\sin\theta_1 = C_1'D_1'\sin\theta$$

$$tg\beta = \frac{2OE}{A'B'}$$

$$tg\theta_1 / \cos\alpha = tg\theta$$

Where P is hydraulic steering cylinder working pressure; D is the diameter of steering cylinder; d is the diameter of piston rod. M is momentary active steering moment in the equation (1) while the vehicle steering angle is θ. As shown in Figure 4, the work of momentary active steering moment is $Md\theta$. W in equation (2) is the total work of active steering moment in the process that the steering angle changes from 0 to θ. For work is Energy , so we can call W the steering ability. While the steering angle is fixed value, the larger the W, the lager the steering ability, and the more easily overcome the large turn resistance, accomplish turning successfully[3-5].
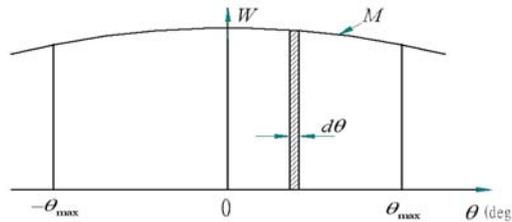

Fig.4. Schematic diagram of steering ability

3. Simulation in matlab

With the above mathematical model of computing steering ability, we can find the relationship between parameters to solve some theoretical problems. In the below, some of the parameters of an articulated vehicles steering system are given.

P=7.06MP=72.04kg/cm2;
AB=500mm; CD=600mm;

OE =900mm; *D*=80mm;
d=45mm; θ =40° .

Using the above parameters, the corresponding program is writen. Through simulation in Matlab, we can gain the figure 5 of the relationship on *W* and α .
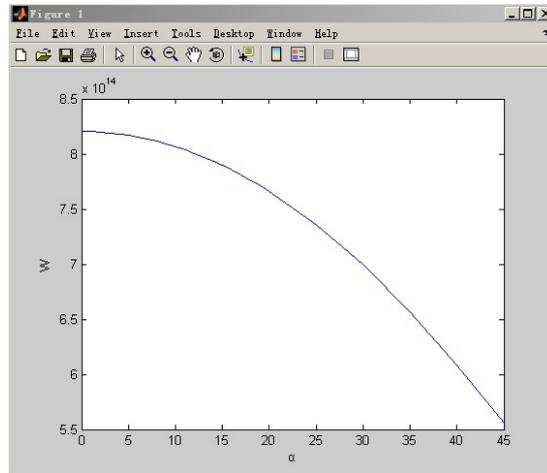

Fig.5. The relationship of W and α

As shown in figure 4, while other parameters are fixed value, we can see steering ability variation trend related to swing angle obviouslly. In the area of the swing angle where α changes from 0° to 15 ^{o} , the steering ability decreases gently. But after α is larger than 20 ^{o} , the steering ability decreases sharply. So we further verify theoretically that experience design of selecting swing angle value is reasonable.

Defining *b*= θ / θ $_1$,we can gain the figure 6 of the relationship on *b* and α .
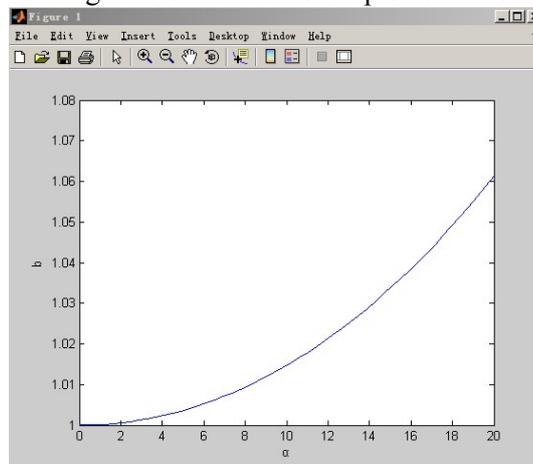

Fig.6. The relationship of *b* and α

As shown in figure 6, *b* increases with α . This means that the vehicle steering angle increases with swing angle while work of cylinder is fixed value. It's known that the larger the steering angle, the more work to overcome resistance is needed. And the steering ability decreases with swing angle, so the lager the swing angle is, the more difficult it is to accomplish steering[6].

4. Optimized Project

For the optimization of articulated steering system, we can select the appropriate weighting factors based on complex degree of road to develop multi-objective optimization model in the design of complex working conditions. Then, we can optimize the hinge positions of steering cylinder in front and rear frame to improve vehicle steering capability and steering angle stability in the structure. We also can optimize steering hydraulic system to increase the active steering torque in enhancing its steering ability.

Constraints:

- For avoiding the pulse of hydraulic fluid to produce vibration and shock, we must ensure the smallest difference of the two cylinder's displacement.
- For accomplishing steering successfully, we must ensure steering active torque is larger than steering resistance torque, which can be shown as the following,

$$M_A > M_R$$

- Steering angle and yaw angle constraints

$$0 \leq \theta \leq 45; \ 0 \leq \alpha \leq 20$$

- Finally, we need to satisfy the boundary constraints and dimensions requirements[7-8].

5. Conclusions

Through the study of articulated steering vehicle with an example, the mathematical model of calculating its inherent steering ability under uneven roads is established. With the simulation software, relationship of steering ability and swing angle is described, which provides a theoretical basis to select the swing angle. Based on this mathematical model, an optimized project of articulated steering mechanism under complex multi-state working conditions is proposed.

In addition, through comparing the active steering torque of various road conditions with the corresponding steering resistance torque, we can monitor the real-time vehicle steering performance. Finally, the mathematical model provides a theoretical basis for other analysis of articulated steering under complex road conditions in future.

6. References

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