



## THE BENDING MODE CONTROL METHOD OF AFS SYSTEM BASED ON PREVIEW CONTROL

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*Abstract-Due to the time-lag of both the mechanical transmission and controller area network (CAN) bus transmission of the Adaptive Front Lighting System (AFS), the actual bending angle of AFS invariably lags behind the steering-wheel angle, which not only makes the real-time response speed of the AFS system slow, but also makes the system stability and the active safety of the vehicle poor. To solve the problem, firstly, the geometrical relations among safety braking distance and the rate of steering-wheel angle and turning radius of the vehicle are analyzed. Secondly, the mathematics model among these variables has been set up. Finally, in order to improve the road illumination of the curve, the control method of bending mode of AFS system based on preview control is proposed. Based on preview control algorithm, the simulation model of the AFS has been built as well as the AFS control experiment platform. After the comparison between preview control and servo control, it can be proved that the preview control method proposed is superior to traditional servo control in AFS system.*

**Index terms:** AFS headlamp, lag of Steering-wheel angle, road illumination, preview model, preview control.

## I. INTRODUCTION

In order to improve the comfort and safety of driving at night, the adaptive front-lighting system (AFS) has been proposed<sup>[1]</sup>. At present, much of the research regarding the AFS headlamp turning control system is servo control systems which mainly used signals of the steering-wheel angle and speed in real time to calculate the turning radius of the vehicle, and so as to control the bending angle of the headlamp. In addition, in order to solve the lag problem in actual process, few previous studies have offered to predict the geometrical radius of the bend through the global positioning system (GPS) and the charge coupled device (CCD)<sup>[2-8]</sup>.

Previous strategies and methods mainly employ the servo control system to control the rotation of the headlamp. However, this has not effectively solved the problem that in the control of the headlamp, the real time turning angle of the headlamp lags behind the intention of the driver. Accidents would easily occur if the driver is not well informed of the bend. Though the problem of lag has been solved in some way, it mainly relies on high-tech equipments instead of being solved through a algorithm.

Researches concerning the AFS headlamp bending angle control system home and abroad mainly employ the method of using present steering-wheel angle and speed to calculate the headlamp's angle to control its rotation. This method primarily eliminated the illumination dark areas when a vehicle was turning at night. However, because of the lag of CAN and the AFS control system<sup>[9]</sup>, the AFS headlamp bending angle invariably lags behind during the turning of the vehicle.

In order to solve the lag of the bending angle, the paper employs the method of using the rate of steering-wheel angle to calculate the turning radius of the vehicle, then makes out the lag of the headlamp, and introduces the method of predicting the future turning radius of the vehicle to decide the lag demand of the headlamp, finally the simulation model of the AFS has been built as well as the AFS control experiment platform, and the results indicate that the safety of driving is improved.

## II. THE LAG OF ADAPTIVEFRONT-LIGHTING SYSTEM(AFS)

### a. The lag of the turning system of AFS

The lag of the turning system is mainly made up of three parts: the time-lag of the control system, mechanical time-lag and time-lag of CAN transfer.

1) time-lag of the control system  $t_{ex}$ : the lagged time of command execution compared with input signals which is caused by the execution of control command.

2) mechanical time-lag  $t_{me}$ : because the gears used for the headlamp are plastic, and there are four pair of them, so the lag caused by mechanical system could not be neglected.

3) Time-lag of the CAN  $t_{tr} \approx 2ms$ : the time-lag of the communication system is the main part of a multitude of experts' researches, it should also be concerned in the headlamp turning control system. The time-lag of the communication system could be got according to document [10].

Through experiment it can be got:  $t_{ex} + t_{me} \approx 40ms$ , so the total time-lag of the system is:  $t_{de} = t_{tr} + t_{ex} + t_{me} \approx 42ms$ .

b. The changing rate of the steering-wheel angle and headlamp bending angle

When turning, the driver would continuously adjust the steering-wheel angle in accordance with the bend, so the relation between the changing rate of the steering-wheel angle and the headlamp angle could be used to solve the lag of headlamp.

With the increasing of the steering-wheel, the actual bend keeps decreasing. Figure 1 manifests the relation between actual bend and primary turning radius.

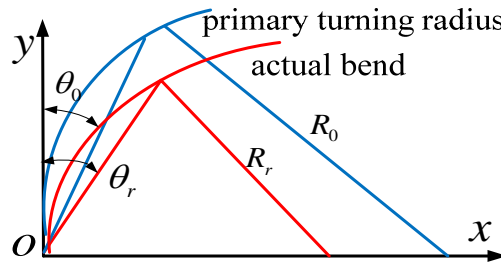


Figure 1 The actual bend and primary turning radius

In figure 1,  $R_0$  is the turning radius calculated with the present bending angle of the steering-wheel. According to the document<sup>[6][11]</sup>, the bending angle  $\theta_0$  of the headlamp is:

$$\theta_0 = \arcsin\left[\frac{1}{R}(0.0047v^2 + 0.2941v + 1.903)\right] \tag{1}$$

Among which  $\delta_0$  is the bending angle of the outer-wheel in the front,  $D$  is the center distance,  $v$  is the present speed, and  $R = \frac{D}{\sin \delta_0}$ .

c. To calculate the lag of headlamp angle

To calculate the lag of headlamp angle when the control system lags, the paper introduces the following calculation model:

The bending angle of the steering-angle is changing at a constant rate, and the speed is constant, that is

$$\begin{cases} \delta = \delta_0 + At \\ v = v_0 \end{cases} \quad (2)$$

Among them A is the changing rate of the outer- wheel angle,  $\delta_0$  is the present outer- wheel angle,  $\delta$  is the outer- wheel angle and  $v_0$  is the present speed.

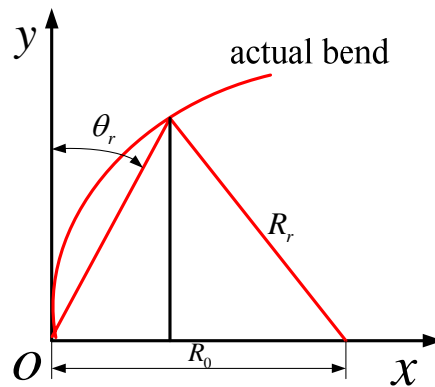


Figure 2 The relation between the actual bending radius and headlamp bending angle  
According to the relation in the figure 2, it could be got that:

$$R_r = \frac{D}{\sin(\delta_0 + At)} \quad (3)$$

So the lag of the headlamp angle can be:

$$\Delta\theta = \frac{180^\circ}{\pi} \arcsin\left[\frac{S \sin(\delta_0 + At)}{2D}\right] - \frac{180^\circ}{\pi} \arcsin\left[\frac{S \sin\delta_0}{2D}\right] \quad (4)$$

And among them:  $S = 0.0094v^2 + 0.5882v + 3.806$ .

In actual turning, the bending radius would not only be influenced by the bending angle of the steering-wheel and the front outer-wheel, but also by the whole design parameters of the vehicle, motion characteristics, and the mechanical characteristics of the tyre. According to the liner two-degree-freedom vehicle model, the actual turning radius is<sup>[12]</sup>:

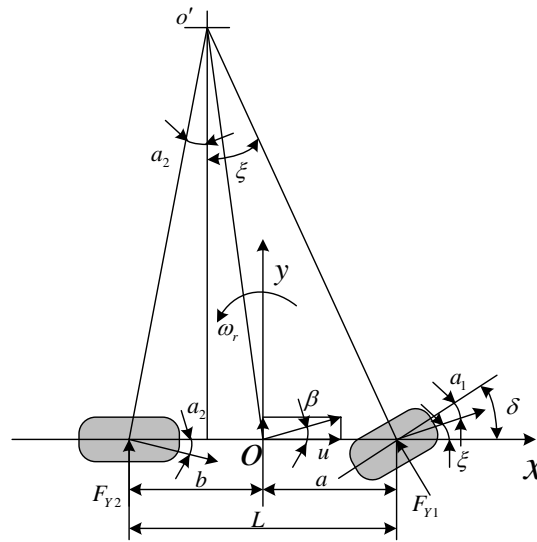


Figure 3 The 2 DOFs vehicle liner model

$$R = \frac{L}{\sin(a_2 + \xi)} = \frac{L}{\frac{\omega_r}{u}(a+b)} = \frac{u}{\omega_r} = (1 + Kv^2)R_0 \quad (5)$$

Taken into equation 2, it could be got that

$$R_r = (1 + Kv^2) \frac{D}{\sin(\delta_0 - At)} \quad (6)$$

$$\Delta\theta = \frac{180^\circ}{\pi} \arcsin\left[\frac{S \sin(\delta_0 + At)}{2D(1 + Kv^2)}\right] - \frac{180^\circ}{\pi} \arcsin\left[\frac{S \sin \delta_0}{2D(1 + Kv^2)}\right] \quad (7)$$

In addition, the above model (7) is calculated when the changing rate of the steering-wheel angle are  $180^\circ/s$  and  $360^\circ/s$ , the results are manifested in figure 4 and figure 5.

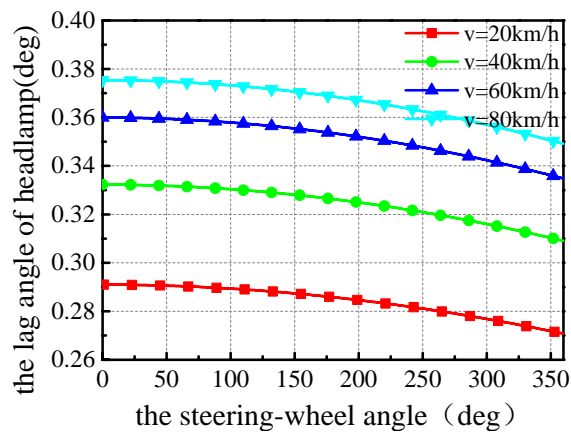


Figure 4 The relation between the headlamp angle lag and the steering-wheel angle at the changing rate of the steering-wheel angle of  $180^\circ/s$

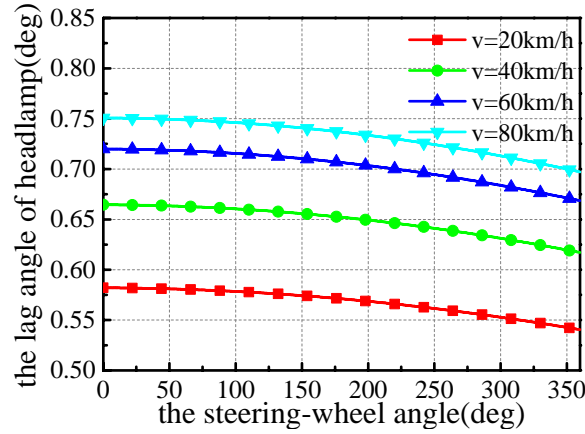


Figure 5 The relation between the headlamp angle lag and the steering-wheel angle at the changing rate of the steering-wheel angle of  $360^\circ / s$

It could be got that, when the speed is constant, the lag of the headlamp bending angle decreases with the steering-wheel angle increasing. When the speed increases, the lag of the headlamp increases. The higher the changing rate of the steering-wheel angle, the more obvious the lag of the bending angle of the headlamp, when the speed is 60km/h, the lag can be  $0.72^\circ$ .

### III. HEADLAMP PREVIEW CONTROL METHOD

In order to solve the lag of the bending angle of the headlamp, the bending mode control method of AFS system based on preview control is proposed. Preview control is composed of the following basic characteristics<sup>[13-16]</sup>.

#### a. preview model

Preview model is a control algorithm based on model. The preview model can demonstrate the dynamic behavior of the system in the future, therefore, just like in system simulation, future control strategies can be given freely to observe output changes under different control strategies [17].

According to the preview control algorithm, if the present steering-wheel angle changes in future, the output preview sequence of the model in the future  $P$  moments would be<sup>[18]</sup>:

$$\tilde{Y}(k) = Y_0(k) + A\Delta\Phi(k) \quad (8)$$

Among them,  $\tilde{Y}(k)$  is the output preview vector of the bending angle of the headlamp. And

$$\tilde{Y}(k) = [\tilde{y}(k+1) \quad \cdots \quad \tilde{y}(k+P)]^T \quad (9)$$

$Y_0(k)$  is the output preview vector if the steering-wheel angle does not change both now and in the future. And  $Y_0(k) = [y_0(k) \ \cdots \ y_0(k)]^T$  (10),  $\Delta\Phi(k)$  is the vector of the control increment.

And  $\Delta\Phi(k) = [\Delta\theta(k) \ \cdots \ \Delta\theta(k+P-1)]^T$  (11),  $A$  is the metric of every control increment.

$$A = \begin{bmatrix} a_1 & 0 & \cdots & 0 \\ a_2 & a_1 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ a_p & a_{p-1} & \cdots & a_1 \end{bmatrix} \quad (12)$$

In the preview control algorithm of the headlamp bending angle,  $y_0(k)$  is the output preview vector if the steering-wheel angle does not change neither now nor in the future. So it could be

$$y_0(k) = \frac{180^\circ}{\pi} \arcsin\left[\frac{S \sin(\delta_0 + At_{de})}{2D(1 + Kv^2)}\right] \quad (13)$$

In the equation 13:  $R$  is the turning radius,  $D$  is the center distance,  $\delta_0$  is the bending angle of the front out-wheel,  $t_{de}$  is the lag of the control system,  $S$  is the stopping sight distance, and

$$S = 0.0094v^2 + 0.5882v + 3.806$$

#### b. Rolling Optimization

In order to ensure the control increment  $\Delta\Phi(k)$  of each period, and guarantee that the control increment can be adjusted in accordance with the present speed, steering-wheel angle and the changing rate, thus to make sure the control system always keeps local optimum, the following performance index should be minimized in every operating period:

$$J(k) = \|Y_r(k) - \tilde{Y}_p(k-1)\|_Q^2 + \|\Delta\Phi(k)\|_R^2 \quad (14)$$

Among them,  $\tilde{Y}_p(k-1)$  is the preview vector of the headlamp bending angle of the past moment to the present moment.  $Y_r(k)$  is the bending angle vector of the headlamp decided by present steering-wheel angle, that is

$$\tilde{Y}_p(k-1) = [\tilde{y}(k|k-1) \ \cdots \ \tilde{y}(k+P-1|k-1)]^T \quad (15)$$

$$Y_r(k) = [y_r(k) \ \cdots \ y_r(k)]^T \quad (16)$$

And among them,

$$y_r(k) = \frac{180^\circ}{\pi} \arcsin\left[\frac{S \sin(\delta_0)}{2D(1 + Kv^2)}\right] \quad (17)$$

$Q = [Q_1 \ \cdots \ Q_p]^T$ ,  $R = [R_1 \ \cdots \ R_p]^T$  are both non-negative scalar, they are error weighting matrix and control matrix respectively, and demonstrate restrains on preview errors and control increment respectively.

Through formula 14 the optimal control increment could be calculated:

$$\Delta\Phi(k) = (A^TQA + R)^{-1}A^TQ[|Y_r(k) - \tilde{Y}_p(k-1)|] \quad (18)$$

That is:  $\Delta\Phi(k) = D[|Y_r(k) - \tilde{Y}_p(k-1)|] \quad (19)$

Among it

$$D = (A^TQA + R)^{-1}A^TQ \quad (20)$$

In this system, A, Q, and R have been given, D can be got through an offline calculation. Only  $\Delta\Phi(k)$  needs to be online calculated.

The dimensionality of preview control system is connected with the effectiveness of rolling optimization, the higher the dimensionality, the more obvious the effectiveness of the optimization, and vice versa. But this does no harm to the functions of the system. The paper chooses only one-dimension parameter, they are:

$$A = 1, Q = 0.8, R = 0.2, \text{ so } D = 0.8$$

And the control increment can be simplified as:

$$\Delta\theta(k) = 0.8[y_r(k) - \tilde{y}_p(k-1)] \quad (21)$$

### c. Feedback Correction

Because of unknown factors like environmental disturbances and inaccurate model matching, the output value of the model may deviate from the actual value. Therefore, at the next sampling, it is prior to detect the actual output value  $y(k+1)$  during the turning of headlamp, then compare it with preview output value  $\tilde{y}(k+1)$  and get the preview error:

$$e(k+1) = y(k+1) - \tilde{y}(k+1) \quad (22)$$

The above formula can be used to evaluate future output error, and revise predictions based on the model. The revised future output prediction can be:

$$\tilde{Y}_{cor}(k+1) = \tilde{Y}(k) + He(k+1) \quad (23)$$

Among them



$$\tilde{Y}_{cor}(k+1) = \begin{bmatrix} \tilde{y}_{cor}(k+1) \\ \vdots \\ \tilde{y}_{cor}(k+P) \end{bmatrix}, \quad H = \begin{bmatrix} h_1 \\ \vdots \\ h_p \end{bmatrix}$$

$\tilde{Y}_{cor}(k+1)$  is the revised output preview vector; H is the revised vector on P dimension, and in this paper,  $H = 1$ .

#### IV. SIMULATION OF PREVIEW CONTROL MODEL

##### a. Simulation model of preview control

According to the preview control algorithm, the control principle<sup>[19]</sup> of the control system is manifested in figure 6:

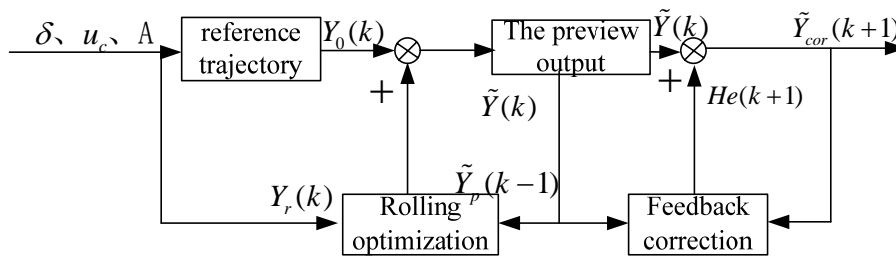


Figure 6 The principle of the preview control of the headlamp bending angle

According to the preview control algorithm<sup>[20]</sup> of the headlamp bending angle, AFS control unit is established, main modules include: preview control algorithm module, stepper motor module, feedback correction module and fuzzy module<sup>[21-24]</sup>.

##### 1) Preview control algorithm module

According to preview control algorithm determined in last section, the algorithm module is manifested in figure 7.

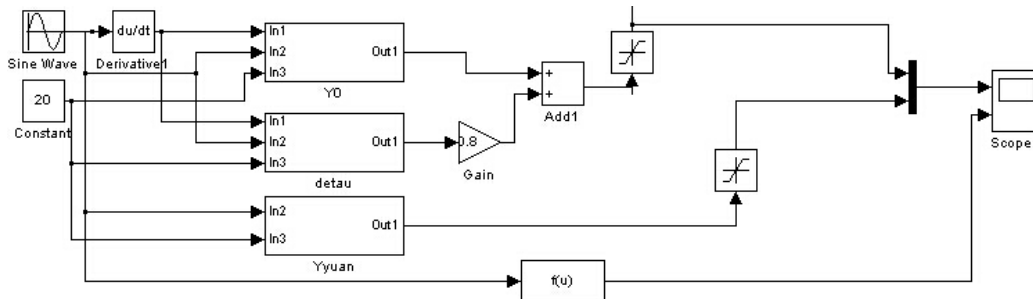


Figure 7 The algorithm module of preview control

In the algorithm, with sinusoidal signal as the input of steering-wheel bending angle, and according to preview control algorithm, predicted output  $y_0(k)$  and rolling control increment  $\Delta\theta(k)$  can be got respectively, the predicted value of bending angle determined by this two value can represent the driver's intention to control headlamp bending angle.

(2) Stepper motor accelerating module

Stepper motor<sup>[25]</sup> needs certain frequency to accelerate, if change from low frequency to high frequency directly, the stepper motor inclined to lose step or even lead to the failure of the motor. Therefore, the stepper motor needs an accelerating process, from low frequency to high frequency so as to guarantee formal operation of the motor. The stepper motor accelerating module is manifested in figure 8.

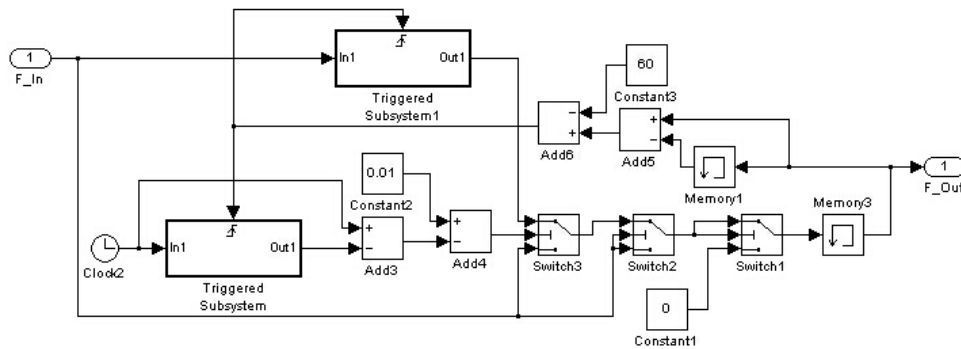


Figure 8 The control module of step motor

(3) Feedback correction module

According to feedback correction algorithm of control, the feedback correction module is manifested in figure 9.

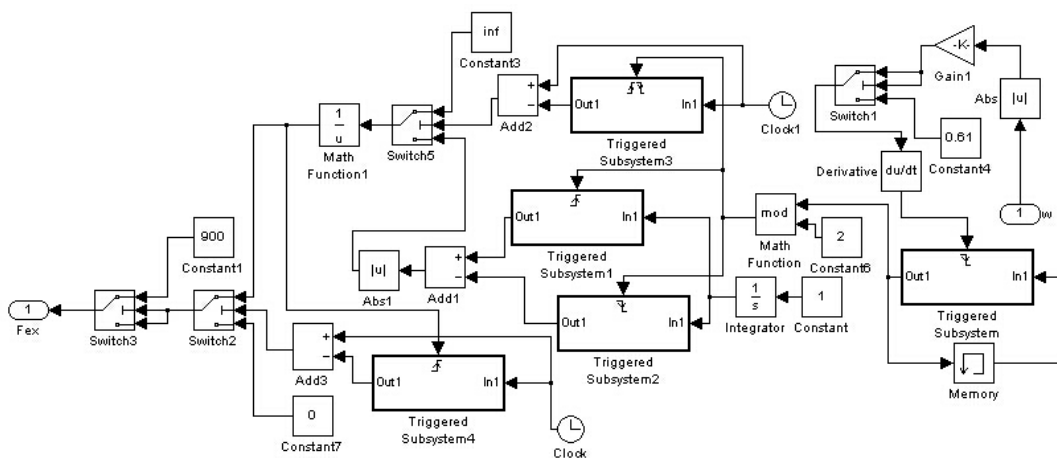


Figure 9 The feedback compensation module

Based on the establishment of above modules of the control unit, the AFS control system simulation module based on preview control algorithm can be established manifested in figure 10.

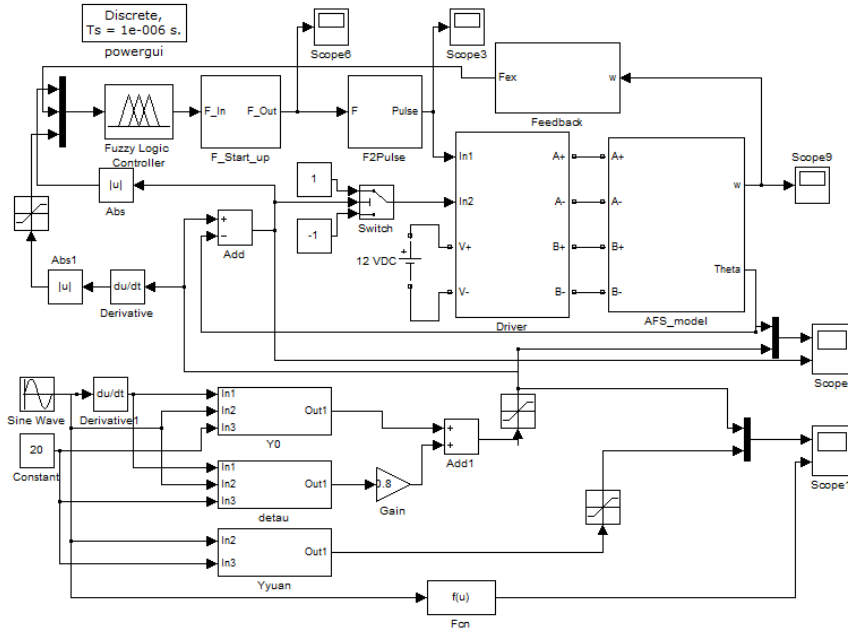


Figure 10 The simulink module of AFS preview control

b. simulation result of preview control model

In this study, it is given that steering-wheel bending angle changes at  $\delta = 540 \sin(\frac{\pi}{4}t)$ , the simulation results are manifested in figure 11 and figure 12 when speed is 20km/h, 40km/h respectively.

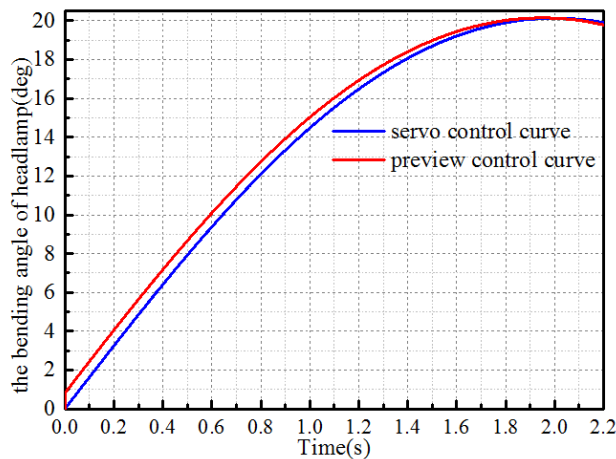


Figure 11 The comparison between preview and servo control at the speed of 20km/h

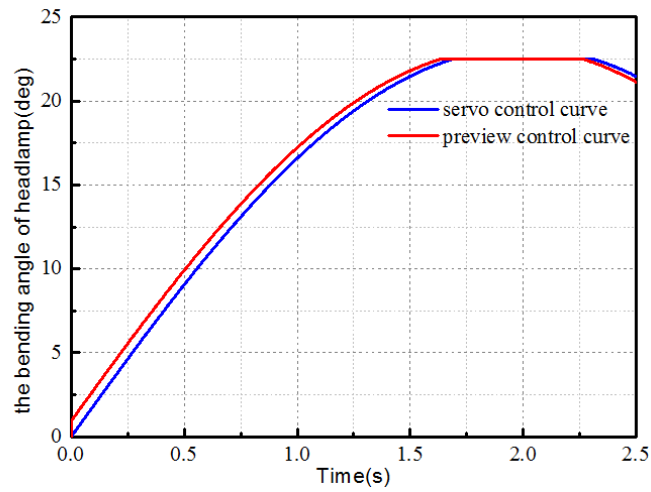


Figure 12 The comparison between preview and servo control at the speed of 40km/h  
 It can be got that, with the continuous changing of steering-wheel bending angle and speed, preview control can ensure certain advances which could avoid lag of headlamp bending angle compared with servo control.

The comparison curve between preview control system and actual output of headlamp is manifested in figure 13, comparison curve between servo control system and actual output of headlamp is manifested in figure 14.

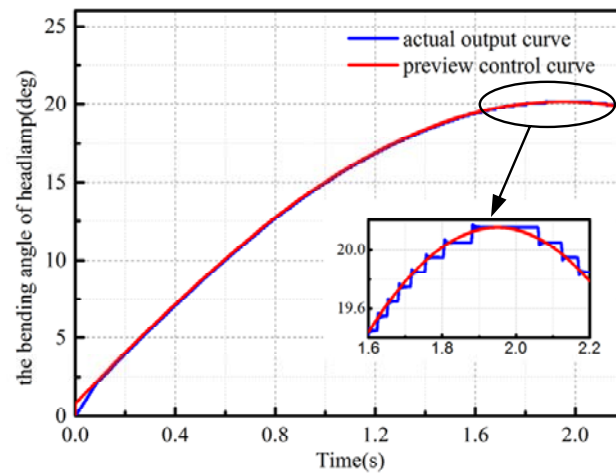


Figure 13 The comparison between predictive control and real tuning angle of AFS

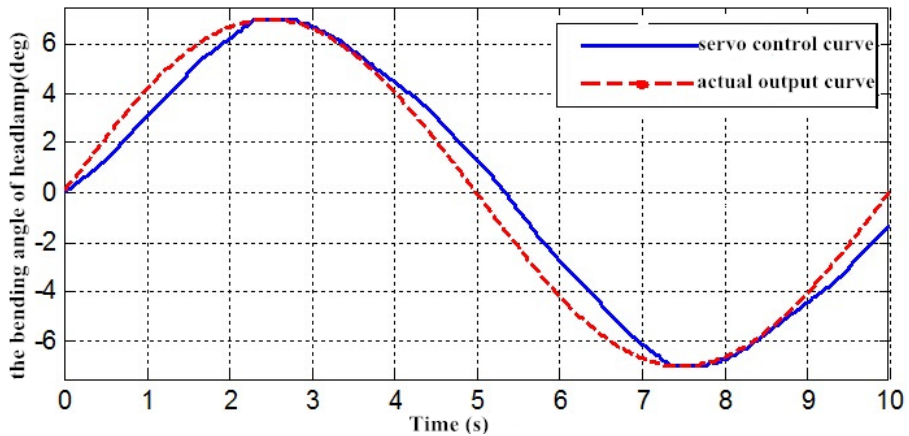


Figure 14 The comparison between servo control and real tuning angle of AFS

It can be got that, in the servo control system, when the changing of bending angle is fast, the follow-up error of the system is big; when changes slowly, the error is small. While in the control system which employs preview control, headlamp bending angle can change with the change of steering-wheel bending angle, the control is better.

Figure15 manifests the partially enlarged view of servo control output curve and preview control output curve. Though the preview control uses current bending angle of the sheering-wheel to estimate future headlamp bending angle, there’s no over control in the system, that is to say the output summit of preview control and servo control are almost same.

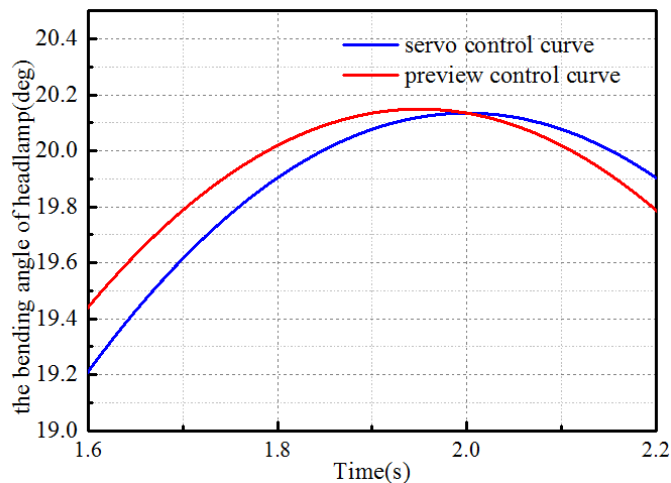


Figure 15 The partial enlarged figure of Figure 11

The preview control model in the paper could effectively solve the lag of headlamp bending angle in the servo control system which is caused by lag of the control system. The changing rate of the bending angle of the headlamp and the steering-wheel could be basically constant and

there will be no over control of the preview control. Therefore, the preview control system established has positive effect which increases AFS system's active safety.

### V. EXPERIMENT OF AFS CONTROL SYSTEM BASED ON PREVIEW CONTROL

AFS control system is composed of AFS platform, microcontroller LPC1752, stepper motor 42BY48LZ-02, laser displacement sensor NCDT1300. The wiring of the whole system is manifested in figure 16.

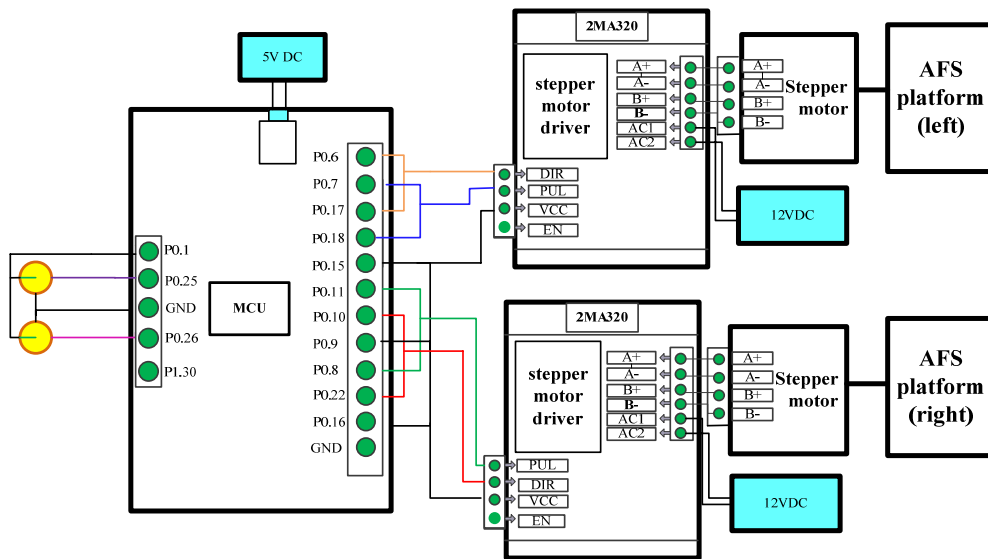


Figure 16 The sketch map of system wiring

The AFS system established is manifested in figure 17.

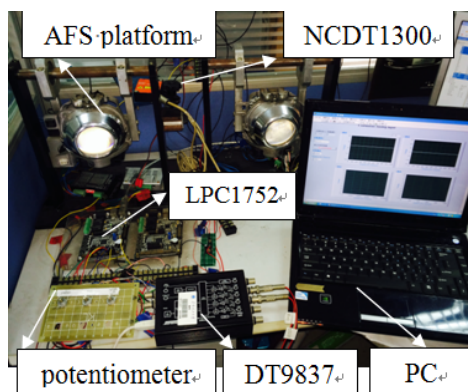


Figure 17 The AFS control system

AFS control platform has done two experiments after establishment, the speed of the first experiment 1 is 20km/h, and experiment 2 is 40km/h, and they respectively use servo control system and preview control system to control headlamp bending angle.

#### a. Experiment 1

The experiment of servo control system would first be done, the speed is 20km/h. With the potentiometer simulating steering- wheel signal to generate signal from  $0^{\circ}$  to  $540^{\circ}$ . The headlamp bending angle can be calculated through servo control system. The sheering-wheel begins to rotate at 2.7s and ends at 4.8s which lasts 2.1s in total, which is equivalent to that the rotational speed of the sheering-wheel is  $257.14^{\circ}/s$ , as shown in figure 18.

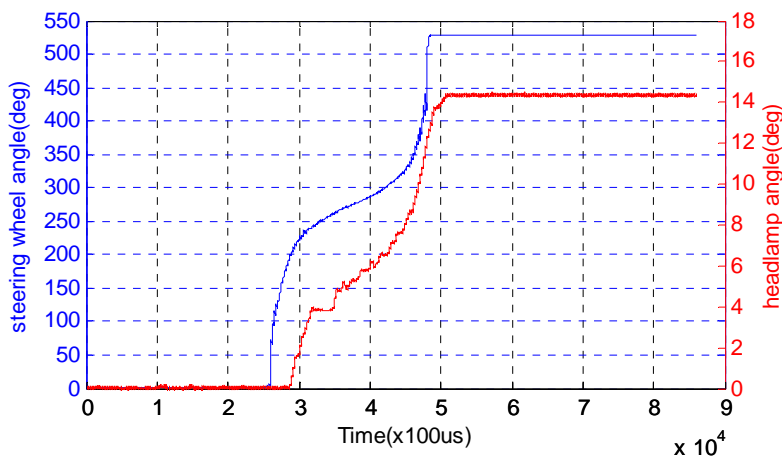


Figure 18 The headlamp angle of servo control ( $v=20\text{km/h}$ )

It could be got through figure 18 that, the headlamp begins to rotate at 2.9s, which is 0.2s lag of steering-wheel bending angle. And at 5.1s, the rotation ends and the lag time is 0.3s, which lasts 2.2s in total, which is equivalent to that the rotational speed of the experiment system of AFS system is  $6.67^{\circ}/s$ .

Carry out the experiment of the preview control system with the same steps, the speed is 20km/h, the sheering-wheel begins to rotate at 2.65s, and ends at 4.65s which lasts 2.0s in total, which is equivalent to that the rotational speed of the sheering-wheel is  $270^{\circ}/s$ , as shown in figure 19.

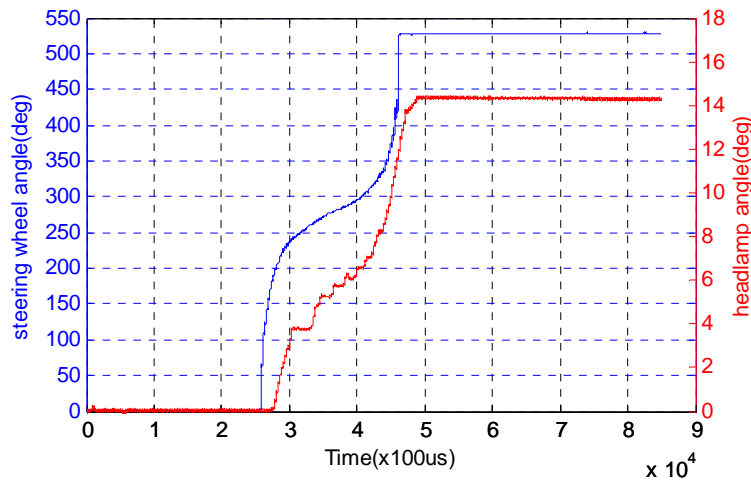


Figure 19 The headlamp angle of predictive control (v=20km/h)

It could be got from figure 19 that, the headlamp begins to rotate at 2.75s, the lag time is 0.1s, the rotation ends at 4.85s, the lag time is 0.20s which lasts 2.1s in total, which is equivalent to that the rotational speed of the experiment system of AFS system is  $6.99^{\circ}/s$

The results imply that, when the speed is 20km/h, the response of preview control system to the sheering-wheel is 0.1s faster than the servo control system, and at the same time, the preview control system has shown better follow effect which proves that the preview control system can reduce time lag of the control system and increase safety when driving at night.

#### b.Experiment 2

The experiment of servo control system would first be done, the speed is 40km/h, with the potentiometer simulating steering-wheel signal to generate signal from  $0^{\circ}$  to  $540^{\circ}$ . The headlamp bending angle can be calculated through servo control system. The sheering-wheel begins to rotate at 2.8s and ends at 5.9s which lasts 3.1s in total, which is equivalent to that the rotational speed of the sheering-wheel is  $174.2^{\circ}/s$ , as shown in figure 20.



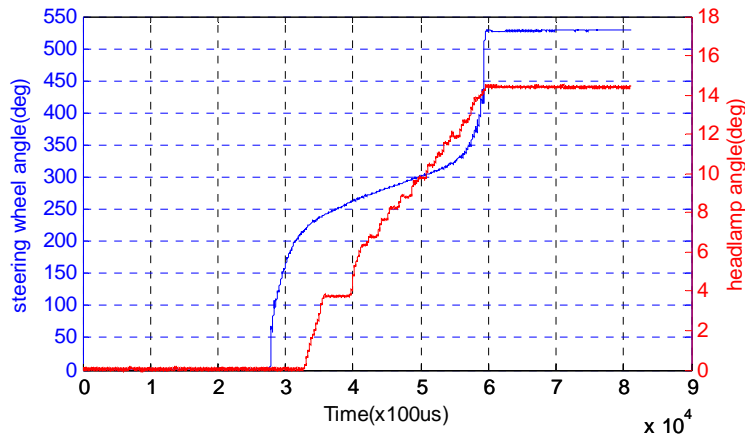


Figure 20 The headlamp angle of servo control ( $v=40\text{km/h}$ )

It could be got from figure 20 that, the headlamp begins to rotate at 3.4s, which is 0.6s lag of steering-wheel bending angle. And at 6s, the rotation ends and the lag time is 0.1s, which lasts 2.6s in total, which is equivalent to that the rotational speed of the experiment system of AFS system is  $5.38^\circ/\text{s}$ .

Carry out the experiment of the preview control system with the same steps, the speed is 40km/h, the sheering-wheel begins to rotate at 2.4s, and ends at 4.75s which lasts 2.35s in total, which is equivalent to that the rotational speed of the sheering-wheel is  $229.8^\circ/\text{s}$ , as shown in figure 21.

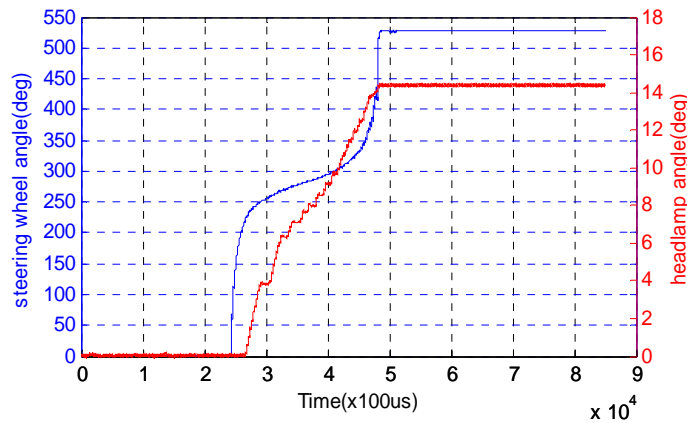


Figure 21 The headlamp angle of predictive control ( $v=40\text{km/h}$ )

It could be got from figure 21 that, the headlamp begins to rotate at 2.6s, the lag time is 0.2s, the rotation ends at 4.75s, the lag time is almost 0s which lasts 2.15s in total, which is equivalent to that the rotational speed of the experiment system of AFS system is  $6.8^\circ/\text{s}$ .

### c. Experiment results

The results suggest that, when the speed is 40km/h, the response of preview control system to the sheering-wheel is 0.4s faster than the servo control system, and at the same time, the preview

control system has shown better follow effect which proves that the preview control system can reduce time lag of the control system and increase safety when driving at night.

Compared experiment 1 with experiment 2, it could be got that, the faster the speed, the bigger the predicted value of the preview control. The bigger the change speed of steering-wheel bending angel, the bigger the predicted value of the preview control and vice verse.

Results imply that, in the headlamp bending angle control system, the headlamp control system based on preview control which taking the reorganization of the driver' intention and introduced in accordance with the driver's intention could reduce the response time of AFS system, reduce the lag of AFS system, which is basically consistent with simulation experiment, it can effectively increase the lighting distance of the headlamp and increase positive safety of the vehicle.

## VI. CONCLUSION

In this study, the significance of researches are as follows:

- 1). To solve the lag of headlamp bending angle caused by lag of control system in the AFS headlamp control system, this paper analyzes relations between AFS system bending angle and turning radius, and between speed and the changing rate of steering-rate angle. In addition, the mathematical model of the relations among the bending angle of AFS system and the steering-wheel, the changing rate of the steering-wheel angle and speed is established.
- 2). To solve the instant response control index (adjusted time, overshoot, stable error and instant error) of the AFS system which is caused by the non-liner relation between the rotation state of AFS system and the rotation speed of the steering-wheel, the AFS turning system based on preview control and the preview control algorithm model is established. The analysis suggests that, the preview control model effectively solves the lag of headlamp bending angle in the servo control system. Meanwhile, the changing rate of the bending angle of the headlamp and the steering-wheel could be basically constant and there will be no over control of the preview

control. The preview control system established in this article has positive effect, which will increase AFS system's active safety.

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