2009 3rd International Conference on Power Electronics Systems and Applications

Development of Electric Vehicle with Advanced Lighting System and All Electric Drive

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Abstract – Different cases of the headlight design has been made for the front-lighting system. The design under pitch control, various obstacle location, control of high and low beam are described. The motion control of the front-lighting system is also discussed. It has found that the stepper motor is preferable than DC motor because of the dynamic performance, cost and the control.

Keywords–AFS, Adaptive front lighting, HID, Automotive, Advanced front lighting.

I. Introduction

Electric Vehicle becomes more popular today. Not even major car manufacturers, small vehicle manufacturers are also developing electric vehicles. Electric vehicle is governmental strategic plan for the next decade because of the environmental needs, capability of the local power electronics technology and the belated development of modern internal combustion engine based vehicles. Various brand and size of electric vehicles are now in the market. New parts and components of electric vehicles are now growing in electric cars domain.

One of the study in this paper is the front-lighting system. The high performance lighting is based called adaptive front lighting system or advanced front lighting system(AFS). There are been considerable research reported on AFS [1-3]. Some basic commercial version can also been found in the market. Most of the commercial motion control is using stepper motor [4]. The paper also discussed the motor performance in nteh AFS.

II. Lighting Control

The control of headlamp consists of two major parts. The first part is the compensation of vehicle pitch to the headlamp. The second part is the control of light beam projection angle in the headlamp. Since the pitch detecting control is well developed and widely used nowadays. No major improvement can be done on the first part. We will mainly focus on the second part.

How vehicle pitch affecting headlamp angle:

Figure 1 Vehicles sits horizontally – Light beams

Since the headlamp is adjusted according to the horizontal level. The headlamp focuses positions correctly.

Figure 2 Vehicles pitch up – Light Beams

When the vehicle accelerates or heavy loaded at the rear of the vehicle, the vehicle will start pitching up. The lamp housing will be pitching up together with the vehicle therefore the focus of the headlamp will go up and higher than the target.

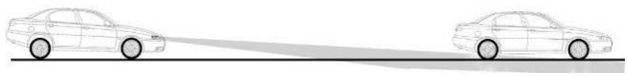

Figure 3 Vehicles pitch down – Light Beams

When the vehicle decelerates, the vehicle will pitch down. The projected area of light will be closer since the angle of headlamp decreases.

The pitch of vehicle changes during acceleration, deceleration and payload varies. Since the headlamp housing is fixed in the vehicle chassis, load sensors have been installed on both front and rear suspension arms. The value feedback from the load sensor can show the pitch angle of the vehicle and compensate the value in the headlamp assembly.

An advanced headlamp system is proposed in this thesis. This new system consists of three major parts. The first part is Automatic High/Low (Hi/Lo)Beam System. The second part is Low Beam Adjustment System. The third part is HID Dimming System. These three systems are working individually on different stages.

Figure 4 shows that there are 3 stages in the system. The first stage represents the range of the nearest obstacles over 50 metres ahead. The second stage represents the obstacles within 5-50metres range and finally the third stage represents the obstacles with 0 - 5metres ahead.

When the system detects an object which is very far away, Automatic Hi/Lo beam system will operates. (Stage 1, Figure 5) When the obstacles go further (Stage 2, Figure 6), the headlamp control will operate. Finally, When the obstacles or cars are very close (Stage 3, Figure 7), HID Dimming System for low beam will take into control. An adjustment will be carried out the angle of headlamp as compensation to the pitch angle of the vehicle. In this case, assuming the pitch of the vehicle is fixed in horizontal position and zero velocity.

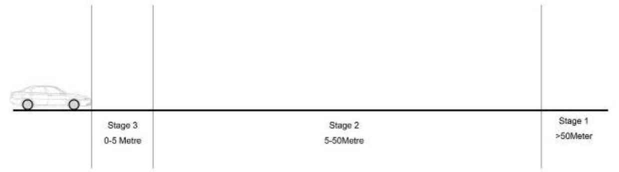

Figure 4 Stages of Advanced Headlamp System

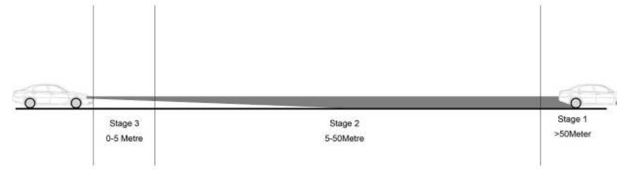

Figure 5 Stage 1 – Obstacle over 50 meters ahead

In Figure 6, the obstacle was detected at the distance of over 50 metres. High beam will be automatically switched on if there aren't any street lamps detected or highest position Low Beam will be maintained.

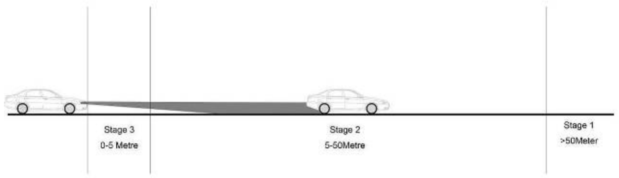

Figure 6: Stage 2 – Obstacle within 5-50metres

In Stage 2, the obstacle was detected in 5-50 metres area. Low beam light will be on and the angle will be adjusted automatically according to the actual distance.

The voltage output by the Ultrasonic Sensor $\boldsymbol{v}$ is inversely proportional to the distance l_1.

$$l_1 = k_{uL} \frac{1}{v} \qquad (1)$$

where k_{uL}: is a coefficient of the ultrasonic sensor. The beam angle of headlamp θ is described by the tangent.

$$\frac{h}{l_1} = \tan\theta \qquad (2)$$

and h is the depressed height.

Angle of head lights is adjusted according to distance in the above cases.

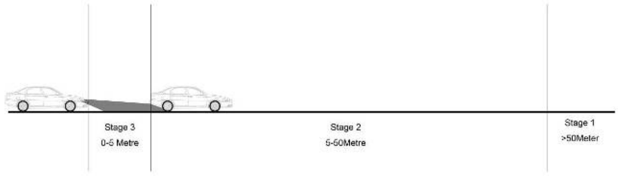

Figure 7 Stage 3 – Obstacles with 5 meters

III. DIMMINMG AND HIGH LO BEAM

A. Light Dimming

HID Dimming Control Circuit is built-in with electronic ballast. There are two methods control to dimming function, Analogue and Digital Control. Dimming control of high power metal halide lamps have been discussed in [5]-[6]. In paper [5] the dimming operation and the influence of the topology on dimming performance is discussed. The dimming operation at low frequency is implemented in [6] and [8]. The dimming control based on voltage control and frequency control is discussed in [8] and [9]. However, the above papers on dimming control are not referred to automotive application. Paper [10-11] introduces dimming control methods for automotive application using analogue methods. It is shown that by controlling the current gain of the controller it is possible to operate the lamp from its rated 35 W of output power to 24 W[11].

Light sensors on the dashboard will detect the light reflected by other obstacles in the front of the vehicle. If the level of brightness is too high which may glare the driver inside the vehicle, the HID lamp will decrease the brightness until it becomes a comfortable level. Since the dimming level of the HID lamp is limited, the Headlamp will be automatically switched off if the level of dimming cannot be met.

B. Automatic High/Low Beam System

The use of high-beam on roads with poor visibility may help the driver but certainly causes glare to the oncoming vehicles. Courteous driving calls for switching to low-beam to avoid glare to the opposite vehicles. Hence, any system that can automatically switch from high-beam to low-beam upon sighting the oncoming vehicle or sensing the surrounding light would be very helpful for the driver.

Automatic High/Low beam system is a system which can switch between high and low beam automatically in response to the detection of light from the oncoming traffic or surrounding light. A block diagram of this system is shown in Figure 9. In this system light sensors on the car upon sensing light either from the oncoming vehicle or surrounding light generate a signal to initiate switching over to low-beam driving. It will revert back to high-beam after fixed no light detection period.

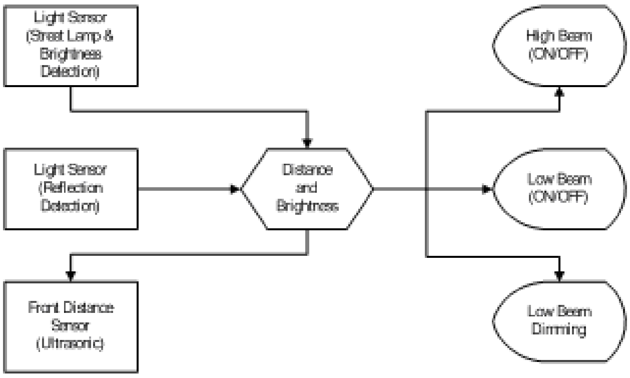

Fig. 9 Automatic Hi/Lo Beam System with speed control

C. Low Beam Level Adjustment

In the present study a method is suggested to improve the performance of the level adjustment scheme discussed previously. In this new system an additional input from a sensor that detects the distance of the oncoming vehicle is used along with the inputs from the vehicle pitch detection sensor and the speed sensor. The distance detection sensor is used mainly to ensure that the projected light does not cause glare to the oncoming drivers and also to enable the low beam to project slightly over a longer distance when there is no oncoming traffic. A block diagram of the control is shown in Figure 10.

The motor used for the level control is a dual coil electric motor. Figure 11 shows a schematic diagram of an H-bridge converter for driving a 2-phase stepper motor. The H-bridge converter facilitates 4-quardant control. The output of the H-bridge converter drives each winding of the motor.

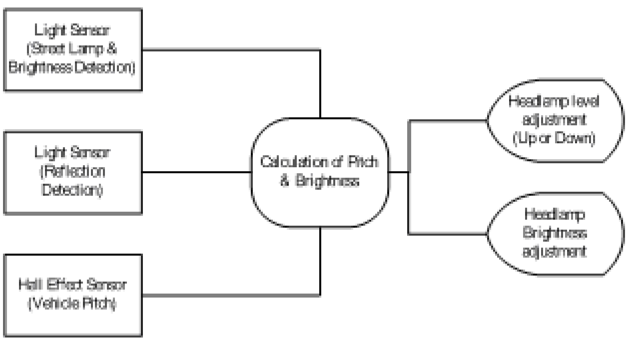

Fig. 10: Low Beam Levelling and Dimming System

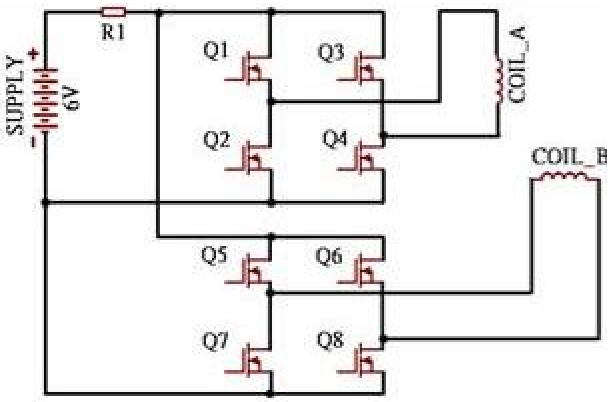

Fig. 11 H-Bridge for Stepper Motor

D. Fail-safe

Since the design of this new system is proved to be reliable, precaution of system failure is still being considered. All the components are continuously monitored by the control unit. Signal is sent to the control unit without interrupting. Once there are any errors detected that will lead to an override of the whole system. The deactivation of the system will maintain the headlamp level in a lowest position with maximum brightness which is the same as a lowest headlamp without active levelling system. This prevents glaring effect to the upcoming traffic and maintaining the visibility to the driver. A warning lamp will illuminate on the dashboard as a reminder to the driver sending the car to the authorized dealer for further diagnosis. Moreover, an error code will be stored inside the controller of this system as well as a warning lamp.

IV. DC MOTOR FOR HEADLIGHT VERTICAL AIM CONTROL

A. Control formulation of the lamp using DC motor

The DC motor has been widely used in industry because it has high power density, large torque and high efficiency. In the proposed automotive headlight system, stepping motor is used because it has simple control structure and easy implementation. However, the performance of stepping motor is affected by the fixed step angle, which leads to a poor position control if one uses a low resolution motor to handle headlight position control. In this section, we will propose an alternative algorithm for headlight vertical by using DC motor. The closed-loop control scheme can improve the speed and position performance in headlight position control. Fig. 12 shows the proposed scheme for dc drive control.

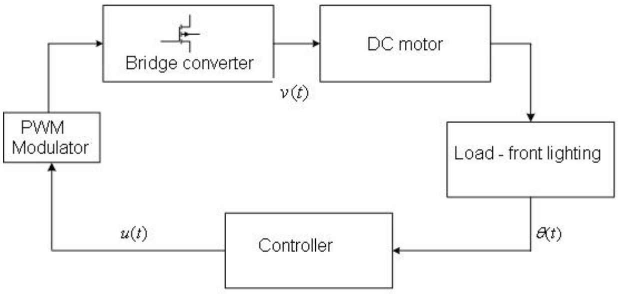

Figure 12 Block diagram of position control

Consider the following DC motor schematic circuit which the equivalent armature resistance *R* and armature inductance *L* are shown:

B. Modelling of the stepper motors

The stepper motor as shown in Figure 13 describes the two windings, B stepper motor. The characteristic equation of the motor is generally described as [4]:

$$L_A \frac{di_A}{dt} = v_A - R_A i_A + K_m \omega \sin(N_r \theta)$$

$$L_B \frac{di_B}{dt} = v_B - R_B i_B + K_m \omega \cos(N_r \theta)$$

$$\tau = K_m (i_B \cos(N_r \theta) - i_A \sin(N_r \theta))$$

$$J \frac{d\omega}{dt} = \tau - B\omega \qquad (6)$$

where

i_A and i_B are the currents of the phase windings A and B.

R_A and R_B are the winding resistance which is assumed to be the same in the calculation

K_m is the motor torque constant

L_A and L_B are the winding inductance and assumed to be equal in the calculation

B is the rotational damping

J is the inertia.

N_r is the number of rotor teeth

τ is the motor torque

$\omega = d\theta / dt$

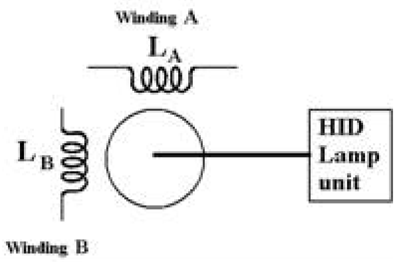

Fig 13 The Stepper motor

The motor parameter is described in Table 1. The Matlab model used for the study is shown in Fig 14. The simulation result is shown in Fig 19.

Table 1: Stepper motor parameters

Parameters	Values
Number of phases	2
Winding resistance R	1Ω
Winding inductance, L	1.4mH
Step angle	1.7 degree
Inertia, J	3.2e-6 kgm^2
Winding rated voltage	6V
Motor torque constant K_m	0.028NmA^{-1}

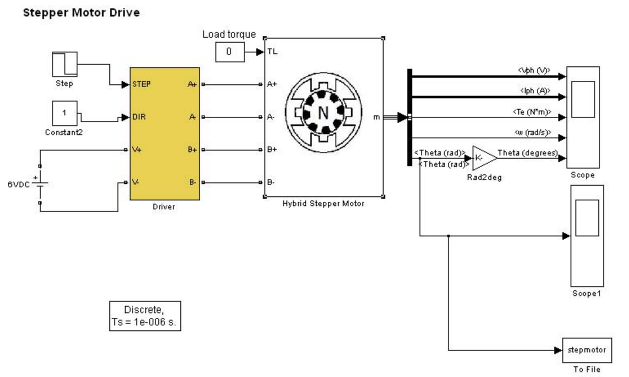

Figure 14 The Mathlab model for the stepper motor

The simulation result is shown in Figure 15. A test using 1 radian rotation is examined for the stepper motor to check the response of the stepper motor. It can be seen that the response time is 0.065 s.

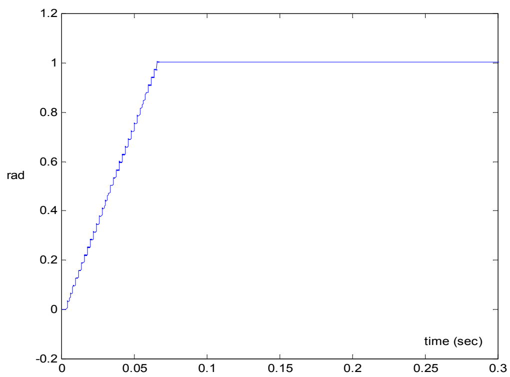

Figure 15 The stepper motor response under a rotation of 1 radian. (1.8°/step, step rate 500/s)

C. Comparison between the DC drive and step motor drive

The aim of the adaptive lamp control is to provide the low cost and simple method control. The response time is important however, it is not very essential for the rapid response because the normal driving time control is very slow as compared with the operation of the motor. Therefore even a rapid response will not affect the overall performance of the AFS. Compare response results for the DC motor and the stepper motor, the settle time for the DC motor is 0.25s whereas the settle time for the stepper motor is only 0.065s. It is confirmed that for the present application, the stepper motor has advantages of a faster response, robust and lower cost. Table 2 shows the comparison of the performance of the two systems:

Table 2:Comparison between the step motor and DC motor

	Step motor	DC motor
Cost	$14	$20
Driver	$18	$15
Power driver	2 H-bridges	One H-bridge
Position control	Simple stepper control	Need PI control for position
Fault free	High fault tolerance	No
Response time Or a set of 1 rad	0.065s	0.25s
Overall comment	Lower cost Simple control Open loop is needed	Higher cost More complicated control PI control or closed loop position is needed

In order to examine which motor is suitable for the AFS, the DC motor and the stepper motor have been used to study the response to the AFS. A model has been developed for the two motors. It is based on the first principle motor model and the torque equation. The model has been examined by programming in Matlab. It has been found that the response time for the DC motor is fast but the settle time is long whereas the stepper motor is very robust and the settle time is much shorter. To compare the cost, the total cost for a stepper motor and lower than the DC motor. No closed loop control is needed for the stepper motor. Therefore it has been recommended that stepper motor is selected for the AFS

V. Implementaion and Analysis of System

A. Control method with the vehicle –vehicle distance

The test system is of a commercially available head lighting system consisting of separate high and low beam reflectors. The lighting system was already equipped with a stepper motor that controls the lever of the reflectors. Two sets of ultrasonic sensors were integrated in the system to collect the information on the distance of the oncoming vehicle. Light sensors were also used to detect the intensity of the ambient light as well as of the light from the vehicle in front.

The controller is designed to respond to conditions based on distance of the vehicle ahead and accordingly it responds to three stages given below.

B. Stage One

In stage one operation, the controller uses the signal from the ultrasonic sensor to switch between high and low beam lightings. This stage basically verifies the ability of the system to respond to the signals based on the distance of the objects ahead. An ultrasonic sensor having a range of over 50 m was used in the experiment. In Bi-Xenon Headlamp modules, the system will control the flap inside the reflectors which control the projection angle of reflects. A few tests have been conducted on this system. Two sensors were fitted on the front of the vehicle. Comparison of signal will be made by the controller which can eliminate noise and increase the resolution.

C. Stage Two

In stage two, the lamp will be in low-beam and the controller basically controls the position of the lamp based on the inputs from the low-range sensor and the hall-effect sensors which detect the absolute pitch angle of the vehicle. The resolution of the low-range ultrasonic sensor is 0.1 m and the sampling period is 0.1 second. The noise is minimized by averaging the measurements every 0.5 second. The controller will adjust the angle of the low-beam in accordance with the measured average value.

In this set of parking aid sensor, the signal is collected from the display of the control unit. The display unit is driving by switch register 74VHC164. The signal from the sensor will go to the control unit and compare with the shift register. The shift register will control the MCU to decode the distance.

The car must be placed on a flat surface and is perpendicular to a screen with an opaque surface 10 meters away. Since there are physical limitations on adjusting the light 10 meters away from a perpendicular screen due to the limited space in the laboratory, the lamp shadow is adjusted in front of a screen with 6-meter displacement. The calculations are explained in the following text.

In the test, the highest point of low beam level is 690mm at the distance of 6 meters. Figure 16 shows the shadows projected by the headlamp such that its vertical level can be controlled by the proposed system.

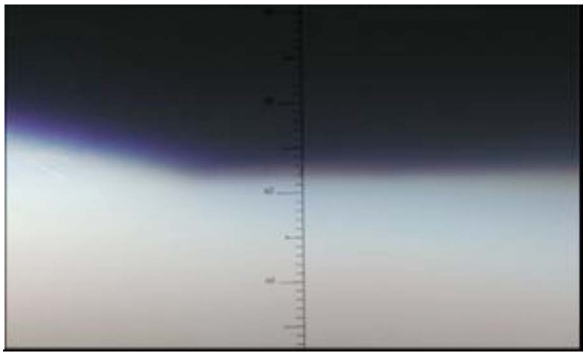

Fig. 16: Marks for measured the headlamp shadow

VI. THE SETUP AND SACKLED DOWN MEASUREMENT

A. Scaled measurement

Figure 17 shows the experimental rig. The motor is integrated inside the front-lamp. The unit is driven by 12V battery system and is obtained from a power supply for the laboratory test.

Fig. 17 Testing Platform of Low Beam Levelling System

The sensors for this test were taken from a scaled down setting so that it can be conducted in the laboratory rather than using 50m test site. The sensor is calibrated for 10% sensor displacement so that now it can be used from 0-5m. For such test condition, a low cost parking ultrasonic sensor can be used.

The internal equivalent diagram of the angle relationship of the stepper motor, and the auction of the lamp unit can be illustrated as in Fig 18. The actual photos of the motor can be seen in Fig 19. The actuation of the lamp movement is done by a levelling system using a lever arm as shown in Fig 18.

Now, height of the lamp h_L = 0.75m, the pitch per revolution l_p=1mm and arm length of the lamp actuator l_a=0.01m.

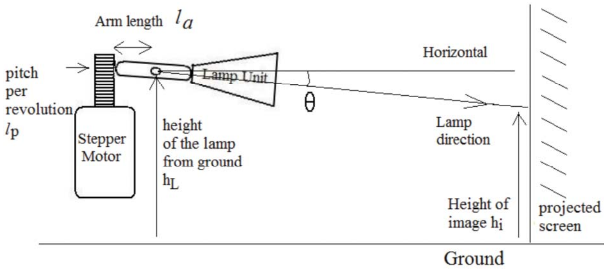

Fig. 18: Illustration of how the stepper motor control the lamp direction

Figure 19 shows the relationship between the height of shadow and distance of the lamp from the screen. A is the distance of the lamp from the screen. B is the height of the projected image. It is the same as h_i.

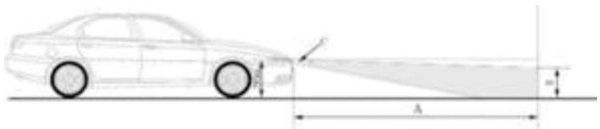

Figure 19 Annotation for short distance test

An obstacle is placed between the lamp and the projected screen in order to trigger the actuation of the ultrasonic sensor and hence to actuate of the stepper motor. The image height h_i was measured in the project screen. The angle of depression (dipped angle) θ is then calculated directly using tangent. The pitch movement l_p is calculated using l_a and tangent of θ. Since pitch per revolution of the motor is 1mm, therefore the revolution for each case is calculated. The response time is difficult to measure. It is done by high speed camera to the image of the screen. The data has been compared with the theoretical of the response time of the stepper motor is shown in Table 3

B. Stage Three

In stage three the controller initiates dimming control upon detection of vehicles nearby. The distance detection is provided by the ultrasonic sensor while the command for the dimming is provided by the light sensors which will detect any reflected light from the vehicles in the front.

Table 3: Measurement of the angle of depression for laboratory test

Distance of obstacle (m)	Measured Image height h_i (m)	Angle dipped θ (rad)	Calculated Pitch movement l_p (m)	Revolution of motor	Response time (s) Measured/ Theoretical
0.1	0.44	0.052	0.000517	0.517	0.23/0.211
0.5	0.44	0.052	0.00517	0.517	0.23/0.211
1.0	0.45	0.050	0.000500	0.500	0.22/0.204
1.5	0.49	0.043	0.000433	0.433	0.19/0.177
2.0	0.54	0.035	0.000350	0.350	0.16/0.143
2.5	0.59	0.027	0.000267	0.267	0.12/0.109

The controller will detect this output and sends a signal to the processor in the HID ballast for dimming operation. The processor then operates the lamp at low power causing dimming of the lamp. The present design has not implemented the dimming control as it is beyond the scope of the project and will be considered for future work.

C. Response of the Step motor control

The step motor can provide a very fast control against the control signal to the motor. To control the lamp for the turn of certain angle can be illustrated in Fig 20. It can be seen that the response time of stepper motor is high for AFS application.

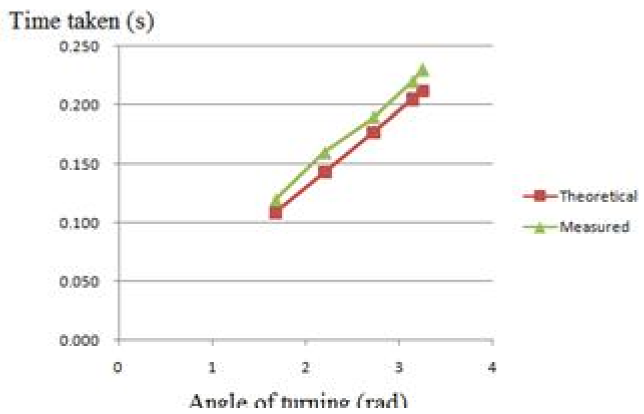

Figure 20 Illustration of the speed of the motor.

VII. Application for this headlamp control system

Headlamp is one of the key components in the vehicle. An efficient headlamp can help to reduce energy consumption in fuel powered vehicles as well as electric vehicles. Since the design of this headlamp control unit has the feature of low power consumption and high power efficient, it benefits the overall range of the electric vehicles.

A. Design equation for EV Car Dynamics

In the process of designing an Electric Vehicle, series of calculations have been done before assembling the running prototype.

The calculation is based on the PolyU EV4 requirement. The initial specifications are:

PolyU EV4 – Total Weight: 590kg; Coefficient of Drag: C_d=0.25; Headwind: 1m/s; Motor Power: 4kW; Largest Cross Section Area: 1.624m^2, Battery: 12V 4x100A

B. Lamp requirement

For the total power of 4kW in the drive. The lighting system accounts for 35W lamp power and 2.5W driver power for each lamp. With 80% efficiency of the ballast. The power for each lamp is 46.2W. Each lamp unit has two HID lamps for Low and High beams. The total power for the AFS is therefore 185W. This is equivalent to near 5% of the motor power.

The system is now all electric with the self-developed work in motor drive, electric system and lighting system. The model EV4 is also developed. Figure 21 shows the implementation of the HID lamp system. The four HID ballasts in a metal package is attached to the chassis as shown. The wire for the ballast to the lamp is made short in order to reduce the EMI. The ballast is connected to both high beam and low beam lamps. The motion control is to actuate the low beam HID. The system has been found working successfully. Figure 22 shows the front side of finished model of EV4. The vehicle is all electric and with the above said specification. The front-lighting system based on the AFS has been developed and working satisfactory.

VIII. Conclusion

This paper describes a control implementation of the system. The control of the vertical level control with the vehicle to vehicle displacement control is explained. The two coil-controls for the stepper-motor are explained. The system has been implemented in the front-lamp. The control waveforms are shown. The response time of the system is fast and is able to provide maximum angle of depression within 0.25 s. The test confirms the functionality of the system built. The AFS based on a stepper motor has been developed. The design method, scaled measurement and the hardware development have been described.

Figure 21 HID installed to the EV4.

Figure 22: The finish model of the EV4

The system is for use in The town car (Neighbourhood Vehicle. The electrical interfacing, battery size, motor size and the users' requirement have been examined. From the experience and the testing for the vehicle for the last 12 months, the development of a power efficient and effective headlamp control unit for a town car can effectively reduce the power consumption and improve the quality of illumination.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of the Teaching Compoany Scheme and the Hong Kong Polytechnic University under the project number RGGN.

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