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Camera Analysis of Commercial Vehicle Camera Monitor System

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Abstract: - This article conducts research and analysis on the camera part of the commercial vehicle camera monitor system, which meets the field of view requirements of GB15084-2022 "Performance and Installation Requirements for Indirect Vision Devices on Motor Vehicles". By calculating the field of view angle of the camera, it is concluded that a camera with a horizontal field of view angle of 120°and a vertical field of view angle of 61.5°can meet the requirements of the field of view angle; The camera adopts a bias design, which can effectively reduce the side distortion of the carriage; The camera heating scheme adopts a heating time of 100s and a heating rate of 0.36℃/s heating logic, which can remove frost on the surface of the lens. This conclusion provides important reference significance for the selection of parameters such as camera field of view angle in commercial vehicle camera monitor systems.

Keywords: Camera Monitor System, Camera, Field of View Angle, Bias Design, Camera Heating

I. INTRODUCTION

Cars are gradually entering ordinary households, and while cars are rapidly becoming popular, they are also accompanied by various related issues, such as safety, comfort, environmental protection, fuel economy, etc[1]. Among them, car safety has always been the most concerned issue for drivers and passengers. In order to ensure driving safety, drivers need to accurately operate according to the road conditions, which requires higher requirements for car rearview mirrors. With the increasing demand for rear view among drivers and passengers, traditional optical rearview mirrors often require an increase in the size of the rearview mirror extension or a change in the overall structure to meet appropriate visual requirements. This measure is bound to result in an increase in the weight of the rearview mirror assembly and an increase in the vehicle's drag coefficient, thereby increasing the vehicle's weight and fuel consumption[2]. To solve the weight problem of the rearview mirror, camera technology can be used to optimize the design of the rearview mirror, reduce the size of the rearview mirror, reduce the wind resistance of the entire vehicle, achieve product lightweighting, and ensure the safety and comfort of drivers[3]. Therefore, analyzing the camera part of the Camera Monitoring System (CMS) is of great research significance.

The camera in the CMS system, due to its large imaging field and digital imaging results, not only solves the problem of blind spots in vehicle vision, but also lays the foundation for image acquisition for assisted driving and intelligent driving. At present, the CMS system composed of cameras has replaced traditional glass mirror systems and become a hot direction in assisted driving technology[4]. The use of appropriate cameras can effectively solve the pain points of direct and auxiliary vision blind spots, rain and fog, strong light, and weak light in commercial vehicles during driving[5].

At present, the world's leading commercial vehicle enterprises have achieved the commercial application of electronic mirrors, and their products are continuously updated and iterated[6]. However, the development of electronic mirrors in China faces difficulties such as lack of regulations, high technical barriers, high development costs, and patent barriers for foreign enterprises[7]. Summarizing the research results of domestic and foreign scholars, the current research on the development of electronic mirror projects and electronic mirror systems mainly focuses on the following three aspects:

(1) Research on the rationality of monitor layout[8]. It is believed that when the monitor size and layout position are fixed in a reasonable position, drivers can simulate driving scenarios such as lane changing, overtaking, and reversing, and conduct comparative analysis with traditional rearview mirrors in the same environment.

(2) Based on the design method of automotive ergonomics[9], different CMS layout schemes for the position of automotive displays were studied. The behavior, characterization, and physiological phenomena exhibited by

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drivers during driving were analyzed, and the impact of display layout on driver behavior and handling during driving was analyzed.

(3) Study the main performance parameters of displays and cameras[10], mainly focusing on magnification, viewing angle, distance from the driver, and resolution.

This article mainly studies the angle selection, bias design, and heating scheme of the camera in the CMS system of heavy-duty commercial vehicles, so that the CMS product has advantages such as smaller wind resistance coefficient, smaller blind spots in the field of view, smaller image distortion, and the use of camera heating to remove frost on the lens surface in low-temperature environments, making driving safer and more comfortable.

II. INTRODUCTION TO CMS SYSTEM

The Camera Monitoring System collects image information through the “eyes" camera of the CMS system, and then transmits the collected image information to the “brain” controller of the CMS system for image processing. Finally, the image is presented to the driver on the LCD screen. Choose a suitable camera to provide a clear indirect view of the vehicle's rear, side, or front view within the specified field of view. The current design approach for CMS is to use a camera, embedded processor, and display solution. The images captured by the camera are processed in the embedded processor and then displayed on the display[11].

At present, the regulations for the CMS system have been opened in Europe and Japan, and China's regulatory system has been launched. In December 2022, GB15084-2022 “Performance and Installation Requirements for Indirect Vision Devices on Motor Vehicles” was officially promulgated[12], which can be referred to in the CMS field of view.

III. CMS SYSTEM CAMERA SELECTION

The CMS system is a disruptive product that replaces traditional optical rearview mirrors in commercial vehicles, demanding very strict requirements for camera optical performance: no distortion, high-quality, safe real-time images, higher ISP firmware requirements, and longer lifespan. At present, there are two main types of cameras in the automotive industry: analog cameras and digital cameras. The digital camera directly converts the light signal into a digital signal, and then processes the image through DSP. The signal is transmitted to the computer through a serial parallel interface, as shown in Figure 1.

Compared with analog cameras, digital cameras have the following advantages: (1) they scan line by line, and each frame of the image is continuously scanned by an electron beam in sequence, one line after another; The motion picture is clear[13]. (2) The resolution of digital cameras can reach over 800TVL, with a resolution of over one million pixels; Simultaneously adapting to existing 1080P high-definition display devices at 16:9, it has a good match. (3) The digital camera adopts ultra-low illumination sensor technology to improve illumination, resulting in low snowflake noise in the image. (4) The output of the digital camera is digital compressed video, without the hassle of electromagnetic interference, and the image is relatively clean. (5) Digital cameras have no bright color separation, high clarity, and more realistic colors.

In order to meet the regulatory vision and road environment requirements in GB15084, digital high-definition cameras are more suitable. From lens sensors, ISP firm ware tuning, to PCB structure design, imaging quality is crucial. Low illumination, wide dynamic range, LED anti flicker, color, white balance, clarity, sharpness, distortion, liquid noise, and so on all rely on the camera[14].

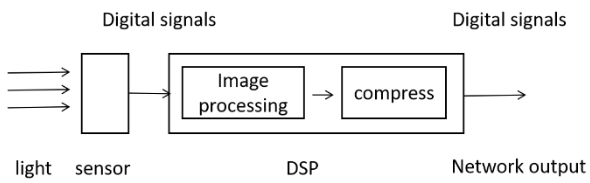


Figure 1: Digital Camera Image Transmission

IV. CAMERAS SUITABLE FOR COMMERCIAL VEHICLE CMS SYSTEMS

A. *Camera Installation Positioning and FOV Angle Calculation*

According to national regulations, heavy-duty commercial vehicles must be equipped with Class II, IV,V, and VI rearview mirrors. Class II rearview mirrors provide external rear view, ClassIVrearview mirrors provide external wide-angle view, Class V rearview mirrors provide blind spot view, and Class VI rearview mirrors provide forward view[15]. The CMS system for heavy-duty commercial vehicles consists of four cameras and three display screens, with a shared camera providing Class II external field of view and Class IV wide-angle external field of view, one on each side, and one camera providing Class V blind external field of view and one camera providing Class VI front field of view, as shown in Figure 2.

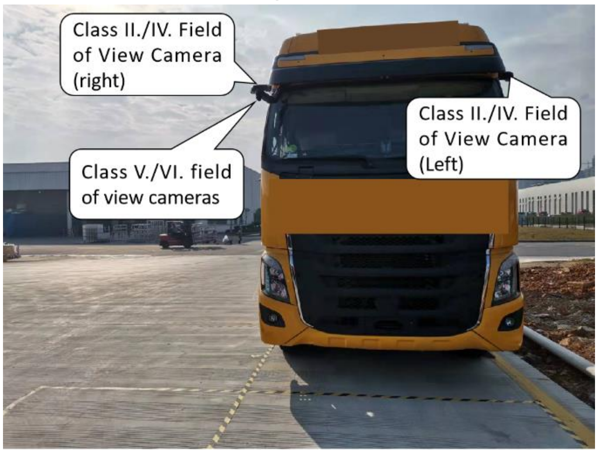


Figure 2: CMS Camera Layout

According to the regulatory system GB15084-2022 “Performance and Installation Requirements for Indirect Vision Devices on Motor Vehicles” in China, the requirements are shown in Figures 3, 4, 5, and 6. Mirrors installed on N-class vehicles must comply with and meet the regulatory requirements for the field of view coverage area[16].

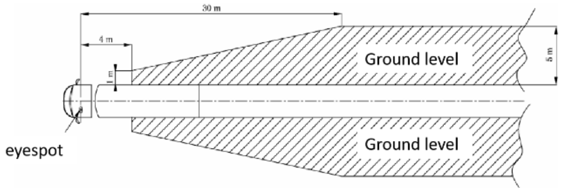


Figure 3: Class II Electronic Outside Rearview Mirror Field of View

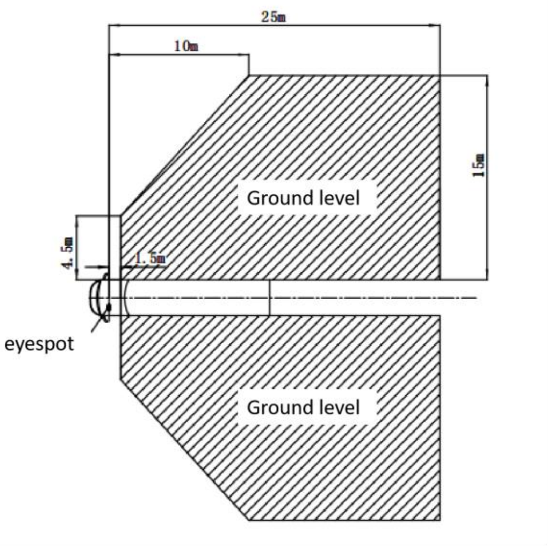


Figure 4: Field of View for Class IV Electronic Outside Rearview Mirrors

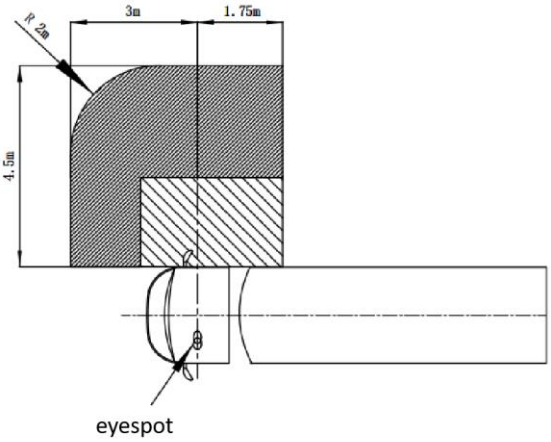


Figure 5: Class V Electronic Outside Rearview Mirror Field of View

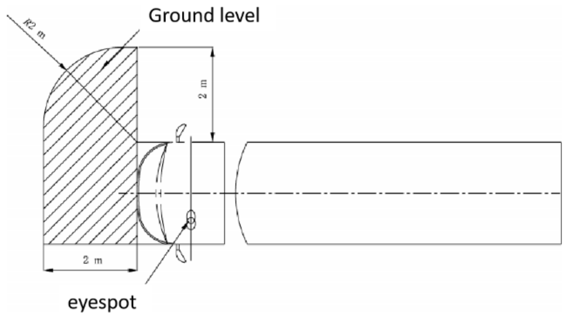


Figure 6: Class VI Electronic Outside Rearview Mirror Field of View

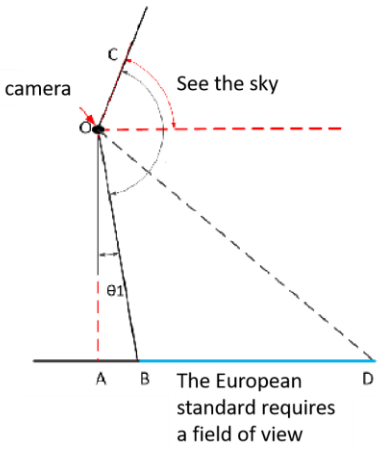
Referring to the installation position of traditional physical mirrors on commercial vehicles, assuming that the installation height of CMS system cameras for Class II, IV, and VIcameras is 3.1m, the camera's field of view angle can be calculated based on the camera field theory calculation model in Figure 7. Figure 7a) Theoretical calculation model for camera vertical field of view, where point O is the camera; OA is the height of the camera from the ground; AB is the distance between the eye point and the camera's field of view boundary, 0<AB ≤ 1.5m; BD is the field of view required by Class II mirror regulations, with BD ≥ 28.5m. Therefore, it can be calculated that θ_1 Angle:

$$\tan\theta_1 = \frac{AB}{OA} = \frac{1.5}{3.1} \tag{1}$$

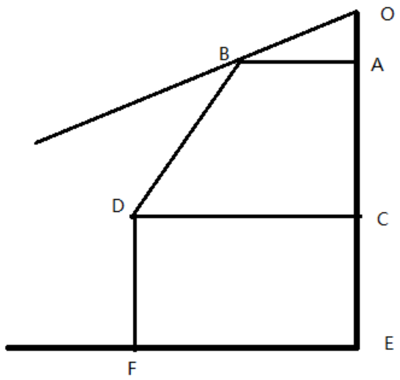
$$\tan\angle AOD = \frac{30}{3.1} \tag{2}$$

Canbecalculated θ_1 is 25.8°, ∠AOD is 84°, ∠AOD is 58.2 °; It can be inferred that a vertical field of view angle greater than 116.4°is sufficient.

Figure 7b) Theoretical calculation model of camera horizontal field of view, region ABCDEF is the field of view required by Class IV mirror regulations, where AB=4.5m, 0A is the boundary of the regulatory field of view to the camera position of 3m, and it can be calculated that ∠BOA=56.3°; It can be inferred that a horizontal field of view angle greater than 56.3°is sufficient. Similarly, the theoretical field of view coverage angle for blind and forward facing cameras can be calculated. After conducting market research on automotive grade cameras, the closest and most readily available digital cameras were selected with a horizontal field of view angle of 120°and a vertical field of view angle of 61.5°for Sony cameras.



a) The Oretical Calculation Model of Camera Vertical Field of View

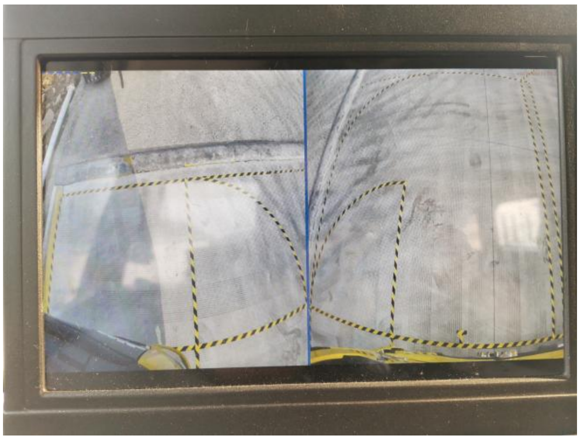


b) The Oretical Calculation Model of Camera Horizontal Field of View
Figure 7: The Oretical Calculation Model of Camera Field of View

B. Camera Installation Site Verification

The CMS system conducts on-site installation verification of the regulatory field of view based on the installation location, selects a suitable empty space, and arranges the Class II, IV, V, and VI field of view areas in advance according to GB15084 regulations. Then, the heavy-duty commercial vehicle equipped with the selected camera is driven to a fixed position to verify the field of view areas of Class II, IV, V, and VI mirrors. As shown in Figure 8, Class II, IV, V, and VI cameras all meet the required field of view according to regulations. Therefore, it is appropriate to choose a camera with a horizontal field of view angle of 120°and a vertical field of view angle of 61.5°.

a) Field Verification Diagram of Class II and Class IV Cameras

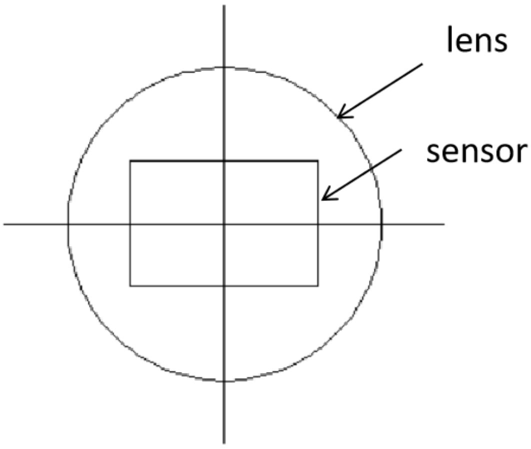


b) Field Verification Diagram of Class V and Class VI cameras

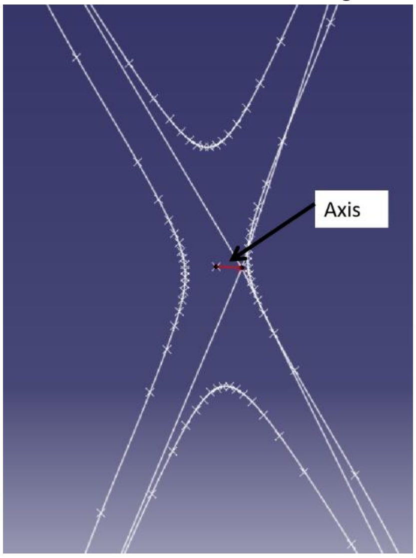
Figure 8: Field Verification of Camera Field of View

C. Bias Scheme for Camera Lens

At present, when designing camera modules in the market, the distortion center position of the lens coincides with the center position of the sensor to ensure the FOV symmetry of the camera, which is a mid mounted camera, as shown in Figure 9.



a) Lens and Sensor Conventional Design Module



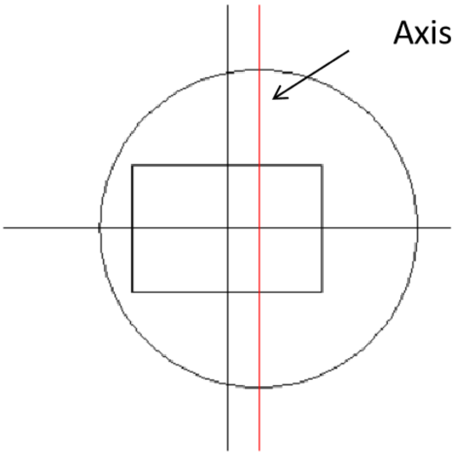
b) Conventional Design Symmetrical FOV

Figure 9: Camera Conventional Design Module Diagram

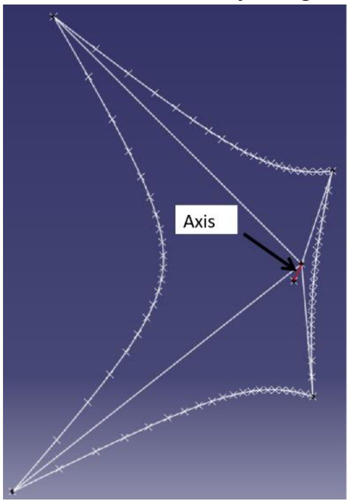
However, installing the central camera on a heavy-duty commercial vehicle may cause the displayed side view of the carriage to be tilted due to the symmetry of the FOV, and the FOV view near the carriage edge may be obstructed by the carriage, resulting in wasted angle, as shown in Figure 11a). In order to meet the required visibility area by regulations, a larger FOV must be used to meet the visibility far from the carriage; At the same time, the size of the sensor needs to be correspondingly increased, which increases the cost.

To solve the above problems, the camera adoptsa center of light bias scheme, and the camera module will generate an asymmetric FOV, as shown in Figure 10. Through this FOV model, we can see the following characteristics:

The FOV in the direction of optical center bias is narrowed, and the distortion is also reduced. It does not waste the FOV angle of the camera, and can ensure the straightness of the side of the rear carriage in the display screen, presenting a realistic picture to the driver.



a) Lens and Sensor Eccentricity Design Module



b) Eccentric Design Symmetrical FOV

Figure 10: Camera Eccentricity Design Module Diagram

The camera installed on the tractor with electronic rearview mirrors of Class II/IV, with an eccentric design compared to a conventional center mounted design, is closer to the center area of the optical axis (side area of the carriage), resulting in better distortion and resolution, ensuring the authenticity and straightness of the displayed image: (1) The carriage edge perpendicular to the road surface in the height direction is displayed straight; (2) The bottom edge of the carriage is parallel to the road surface display; (3) Minimize the distortion around the carriage, as shown in Figure 11.

a) Mid Position b) Bias

Figure 11: Comparison of Camera Center and Bias Effects

D. Heating Scheme for Cameras

In adverse weather conditions, the rearview mirror may form frost or water vapor on the camera due to weather or temperature changes, affecting the driver's field of view and posing a significant safety hazard[17]. As a key core component of visual perception in electronic rearview mirrors, the camera is installed outside the vehicle to monitor the surrounding environment, helping users obtain a clear view and safe driving. However, due to the camera being installed externally, differences in ambient temperature can cause water mist or frost to appear on the lens, resulting in the driver being unable to clearly observe the external environment and affecting driving safety[18]. At present, most of the methods used are to apply a hydrophobic film treatment to the surface of the camera lens or add a defrosting device, which can have a certain effect, but cannot quickly defrost and defog.

Adopting a camera with a heating device, comprising a housing, wherein the upper half of the housing is used for mounting the lens, and the lower half is used for installing the camera's motherboard components and heating device; The heating element is adhered to the inner and surrounding sides of the lower half of the shell, as shown in Figure 12. When the heating element starts working, the heat is quickly transferred to the entire casing through the camera housing, which can effectively prevent water mist and frost from obstructing the view; There is a temperature sensor installed on the motherboard. When the temperature of the cavity reaches the offline threshold, the heating element starts to work; When the temperature of the cavity reaches the upper limit threshold, the heating element stops heating; This can achieve automatic heating; Users can also manually control the heating of the camera, effectively preventing the camera from being obstructed by water mist and frost, expanding its wide range of usage scenarios and market prospects.

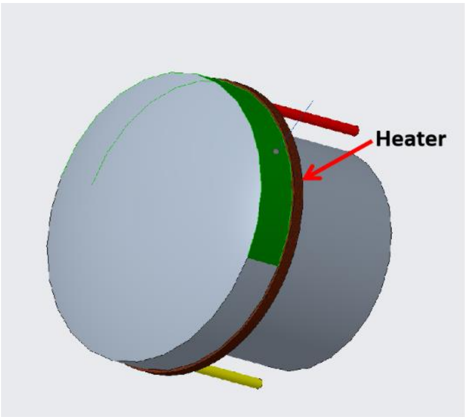


Figure 12: Camera Heating Structure

Place the heated camera in an environment of -30℃ and -40℃ for 2 hours, then move it to the ambient temperature for 3 minutes to allow the water to solidify. Then, move it to an environment of -30℃ and -40℃ for

0.5 hours to freeze the water droplets on the mirror surface. Start heating and record the defrosting time, as shown in Tables 1 and 2;

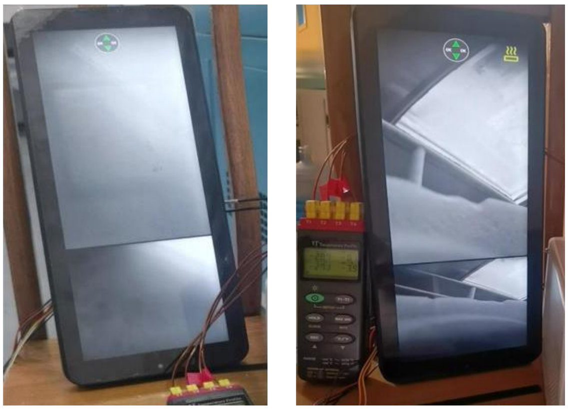
The average time required to remove frost from the lens surface in an environment of -30℃ is 70 seconds, and the average defrosting rate is 0.33℃/s; The average time required to remove frost from the lens surface in an environment of -40℃ is 98.5 seconds, and the average defrosting rate is 0.36℃/s; Therefore, the heating logic of the camera heating device can be preliminarily determined, with a heating time of 100 seconds and a heating rate of 0.36℃/s, which can ensure that the frost on the surface of the camera lens can be completely removed, as shown in Figure 13.

Table 1: Heating Defrosting Table for Cameras at -30℃

Serial Number	Surface temperature of lens before heating/℃	Surface temperature of lens after defrosting/℃	Defrosting time/s	Defrosting rate (℃/s)
1	-27.8	-4.4	75	0.31
2	-27.7	-3.5	75	0.32
3	-27.8	-7.1	62	0.33
4	-27.5	-4.6	68	0.34
average value		-4.9	70	0.33

Table 2: Heating Defrosting Table for Cameras at -40℃

Serial Number	Surface temperature of lens before heating/℃	Surface temperature of lens after defrosting/℃	Defrosting time/s	Defrosting rate (℃/s)
1	-36.9	-0.5	90	0.4
2	-36.4	2.5	107	0.36
3	-37.7	-1.5	101	0.36
4	-35.8	-6.2	96	0.31
average value		-1.43	98.5	0.36



a)Before Defrosting b)After Defrosting

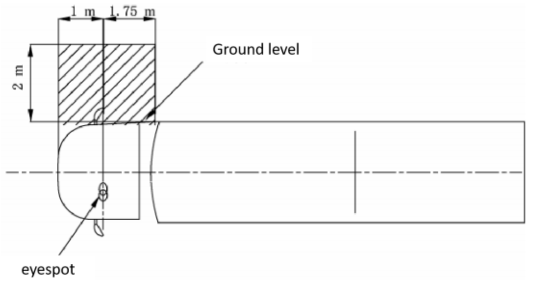
Figure 13: Comparison of Camera Heating and Defrosting Display before and after

V. THE ADVANTAGES OF CMS SYSTEM CAMERAS

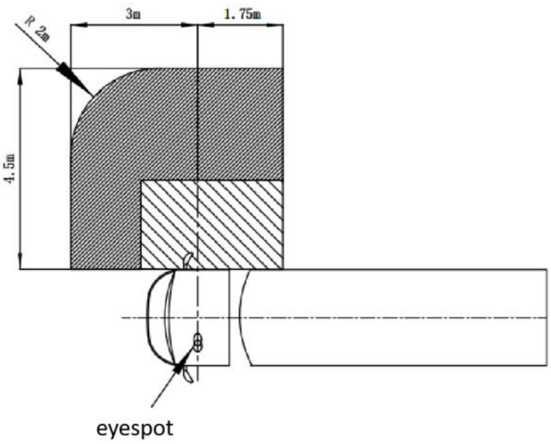
A. Reduce Wind Resistance/Noise

When using traditional physical rearview mirrors, due to the limitations of lens curvature and structure, there are a total of four mirrors installed on heavy-duty trucks, namely driver's side Class II and IV rearview mirrors, passenger's side Class II and IV rearview mirrors, driver's side blind filling Class V rearview mirrors, and front lower blind filling Class VI rearview mirrors. The entire set of mirrors has a large windward surface and no advantage in overall weight. At the same time, due to the difference in structural surface with the vehicle body, there may be “howling" and “wind noise" during high-speed driving; The latest regulations issued in GB15084-2022 have increased the coverage range of Class V regulations from 2000mm*2750mm to 4500mm* 4750mm compared to GB15084-2013, as shown in Figure 14. This further increases the structure and weight of the physical rearview mirror, while increasing the field of view, the area of the outer rearview mirror lens also increases. In order to ensure a better observation area, the volume of the exterior rearview mirror cannot be further reduced, which also leads to poor drag coefficient[19].

This is not a problemin the CMS system. The external camera mechanism replaces traditional rearview mirrors, and only requires the installation of a camera support arm on the driver's side, a camera support arm on the driver's side, and a camera support arm at the front and bottom to greatly reduce the weight of the structure while meeting regulatory vision. Its volume can be reduced to one-fifth the size (or even smaller) of traditional rearview mirrors, The overall design can be more in line with aerodynamic principles, and high-speed wind noise will also be reduced significantly[20].



a) GB15084-2013 Class V Regulatory Vision Area



b) GB15084-2022 Class V Regulatory Vision Area

Figure 14: GB15084 Regulation 2013 and 2022 Class V Field of View

B. Broader Vision

The curvature, shape, and size of traditional reflective mirrors are fixed and unchanging, so the field of view is also limited and can only be adjusted slightly through mechanical structures. Therefore, during driving, people often twist their heads and bodies to gain a larger view. Especially when heavy towing trucks are towing, in reverse and turning scenarios, due to the large angle between the carriage and the front of the vehicle, the physical rearview mirror cannot clearly see the view behind the rear of the vehicle. Therefore, manual intervention is needed to command from the rear of the vehicle, and the large blind spot increases the risk of accidents and also increases the efficiency of reversing.

And the small and exquisite camera allows us to not be limited to theconfiguration of one rearview mirror on each side. By installing cameras with different angles and fields of view, we can obtain the entire side or even panoramic image of the vehicle through real-time signal acquisition software calculation, or focus on observing a certain area, so that blind spots, especially when reversing or turning, no longer exist, further ensuring the safety of vehicle driving and other road participants.

C. Less Affected by Weather

Due to the fact that traditional rearview mirrors use the principle of reflection of light from mirrors, in adverse weather conditions such as rain, snow, and fog, the rearview mirror lenses will be covered with fog or water droplets, and in addition, the window glass will become foggy; In low light conditions at night, the rearview mirror is dim and it is difficult to see the environment behind the vehicle clearly; In a strong light environment, the headlights of vehicles behind at night or direct sunlight during the day can cause lens halo and unclear visibility, which greatly affects driving safety.

In contrast, electronic rearview mirrors only need to have waterproof and heating functions in place, and the rest can be handed over to later algorithms and the car's display screen. Even in harsh weather conditions such as rain, snow, fog, night, low light, and strong light, the rear image is still clear and visible.

D. Less Affected by Environmental Brightness

At night or in low ambient brightness, it is difficult to seeclearly the situation behind the vehicle's side on traditional rearview mirrors. The electronic rearview mirror uses a low light camera, which can display the surrounding images of the vehicle as clearly as during the day, even if the ambient brightness is less than 0.1 Lux.

VI. CONCLUSION

The CMS system is mainly divided into three modules, namely the monitor system, controller system, and camera system. The camera is mainly used to capture images, and the quality of the captured images has a significant impact on the entire CMS system. Based on the above research, the following conclusions are drawn in this article:

(1) For the selection of heavy-duty commercial vehicle cameras, a camera with a horizontal field of view angle of 120°and a vertical field of view angle of 61.5°can meet the requirements of field of view angle, reduce blind spots, and make driving safer.

(2) For cameras installed on heavy-duty commercial vehicles, a bias design is adopted to reduce distortion in the side area of the carriage near the center of the optical axis, ensuring the authenticity and straightness of the display image.

(3) For environments with frost on the surface of low-temperature cameralenses, the heating logic of the camera is set to a heating time of 100 seconds and a heating rate of 0.36 °C/s, which can remove all frost on the surface of the lens, ensure the clarity of the display image, and reduce safety risks.

The shortcomings of this study lie in the lack of systematic research on cameras, and only the special requirements for cameras applicable to commercial vehicle CMS systems are studied; In addition to the parameters studied above, there are many important parameters that have a decisive impact on the performance of cameras, such as lens material, lens coating process, image sensor, resolution, S/N, HDR, LFM, frame rate, minimum illumination, depth of field, etc. These will be the future research directions.

Overall, the CMS system has advantages such as energy conservation and consumption reduction, improved range, reduced blind spots in direct and indirect vision, better visibility under harsh working conditions, and other expandable and diverse functions and features to ensure driving safety. Especially in terms of energy consumption, it can make a significant contribution, which is in line with the "carbon peak" and "carbon neutrality" strategies proposed and promoted by China. CMS has a large market space and application prospects. Future CMS may integrate more intelligent auxiliary functions, such as blind spot detection, lane departure warning, traffic sign recognition, etc., to enhance driver safety and convenience. At present, domestic CMS products have not been mass-produced yet. Relevant departments should guide and support CMS products, increase research and development, localization, reduce costs, and promote better promotion of CMS.

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