Investigation into the Technological Advancements and Standardization of Automotive Lighting Systems

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Abstract. With the development of automotive intelligence, automotive lamps are no longer only parts that provide lighting functions, but have become multi-functional parts that integrate lighting, interaction and entertainment, playing an increasingly important role in improving vehicle safety and interactivity. This paper analyzes the development of automobile lighting technology, introduces the automobile lighting standards under different systems, expounds the development direction of automobile lighting standardization work, and provides ideas for the standardization work of automobile lighting in the future.

Keywords: Lighting technology, Intelligent lighting system, Standard research, Standardization requirements.

1. Introduction

In the modern transportation system, automotive lighting is not only the basic guarantee for the safe driving of vehicles, but also an important part of automotive design and technological innovation. With the rapid development of the automobile industry and the increasingly complex road traffic environment, the role of automotive lighting systems is becoming more prominent. From basic night driving lighting to various auxiliary lighting functions to improve driving safety, automotive lighting plays an irreplaceable role in enhancing the driver's vision, improving driving identification and reducing the risk of traffic accidents.

The rapid development of automotive lighting technology not only promotes the improvement of product performance but also poses new challenges and requirements for the formulation of relevant standards. To respond to the development trend of automotive lighting technology and ensure the safe application of new lighting technologies, standards should be formulated and revised under the premise of ensuring safety, fully exerting their unlimited potential in automotive intelligence. This paper analyzes the development history of automotive lighting technology, introduces automotive lighting standards under different systems, and expounds the development direction of automotive lighting standardization work, providing ideas for future automotive lighting standardization work.

2. The Evolutionary Process of Automotive Lighting Technology

Automotive lighting fixtures are constantly updated and iterated in three aspects: light source, technology and function. The headlight source has developed from the initial kerosene lamp to today's laser headlight; The wave of automobile intelligence and the continuous iteration of the underlying technology are promoting a huge change in headlight technology; The function of car lights has also undergone a transformation from traditional lighting to a new type of interaction.

2.1 Light source.

Early automobiles used fuel lamps, such as paraffin or acetylene lamps, which were of limited brightness and posed safety hazards. With the development of electric power technology, incandescent lamps gradually replaced fuel lamps. Incandescent lamps have higher brightness and better stability, but higher energy consumption, and relatively short service life. Halogen lamps are

an improved type of incandescent lamps, by filling the bulb with halogen gas, the luminous efficiency and life of the bulb is improved. Halogen lamps are widely used in automotive headlamps, but still have the problem of high energy consumption. Xenon lamps produce only two-thirds of the energy consumption of halogen lamps, using the high-pressure gas discharge principle, which can provide a more stable and brighter lighting output, emitting a bright white light colour, creating a better visual experience for drivers, thus entering the public's field of vision [1]. Nowadays, automotive lamps have entered the era of LED lamps.LED lamps use light emitting diodes as the light source, which have the lowest energy consumption and the longest service life, and are able to achieve instantaneous illumination to meet the emergency response needs of the vehicle during driving. Figure 1 shows the development of Audi car lights.

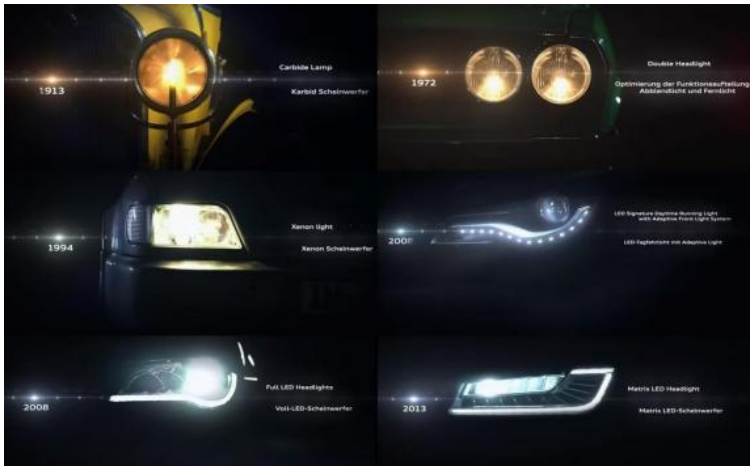

Fig 1. Audi lights history

Laser headlamp is a new type of light source appeared in recent years, by focusing the laser beam, forming a high brightness lighting effect, with very high luminous efficiency and extremely long irradiation distance, at the same time can according to the road and the traffic situation in real time to adjust the illumination angle and brightness, which greatly improves the driving safety [2].

2.2 Technology.

LED Matrix Headlamps, with multiple LEDs arranged in rows, columns or matrices, are the basic solution for entry-level multi-pixel smart headlamps. Compared with ordinary LED headlamps, LED matrix headlamps are a more complex secondary optical system that assigns light to each LED so that it becomes an individual pixel.LED matrix headlamps allow precise control of the illumination area, which can be selected to illuminate a specific area or select some areas to be shaded [3]. Figure 2 shows the schematic diagram of LED matrix headlamps.

Fig 2. LED matrix headlamps

LCD (Liquid crystal display) technology the prevailing mainstream display technology, has emerged as a preferred solution for intelligent headlight source systems, facilitating the convergence of projection functionality and high-pixel illumination [4]. DLP (Digital Lighting Process)

technology is based on digital light processing, which controls the direction and intensity of light through the DLP technology is based on digital light processing, through the digital micromirror device (DMD) to control the direction and intensity of the light, to achieve high-precision lighting control. DLP's high resolution makes it not only to achieve the function of the matrix headlights, but also through the supplier to provide the programming function to achieve a variety of personal lighting modes, is the current mainstream of the realization of the projection function of the digital headlamps.The size of the LED in the microLED is usually less than 100 μm, which can also achieve the projection function, and have the advantages of low cost and light weight. Figure 3 shows the schematic diagram of headlight projection.

Fig 3. Headlight projection

2.3 Function.

AFS is a system that automatically adjusts the direction and range of the headlight beam based on information such as the vehicle's driving status, steering wheel angle and speed. Cars equipped with AFS can achieve seven modes of illumination, including country road mode and motorway mode. This intelligent adjustment not only reduces the trouble of manual operation by the driver, but also improves driving convenience and safety.

ADB is a kind of intelligent high beam control system that can adaptively change the high beam light type according to the road conditions, using the front view active safety camera and other sensors to capture real-time information about the road ahead, then automatically turn on or off the high beam for the driver according to the driving status of the vehicle, the environmental status, and the status of the road vehicle. It is also able to adaptively change the high beam light pattern according to the position of the vehicle in the field of view in front of the vehicle in order to avoid causing glare to other road users [5].

DLP, Micro LED and LCD technologies enable headlights to be transformed into projectors that project symbols on the road to convey information to traffic participants, such as traffic sign reminders and turn-by-turn projections. As a visual component, headlights are expected to become the core carrier of vehicle data flow output, thus realising the functional upgrade from ‘illumination’ to ‘expression’.

With wider viewing angle, thinner and lighter structure, and more uniform and softer luminescence, OLED can be freely designed with different shapes and sizes of light-emitting units [6]. This refined light-emitting partition design can create vivid dynamic effects and three-dimensional symbolic modelling. Figure 4 shows the schematic diagram of the reversing light personal expression.

3. Standardization Status and Challenges of Automotive Lighting Fixtures

3.1 Status of research on international standards and regulations.

At present, the international standards and regulations on automotive lighting fixtures are mainly divided into three systems: the U.S. SAE system and FMVSS standards, the European UN system and ISO system.

In the 20th century, 3, 40 years, the U.S. Society of Automobile Engineers (SAE) issued a number of motor vehicle lighting standards, covering vehicle headlights, turn signals, brake lights and other types of light performance requirements, the initial formation of the motor vehicle lighting standards system structure. U.S. Department of Transportation, National Highway Traffic Safety Administration in the United States ‘National Traffic and Motor Vehicle Safety Act’ under the authority of the development of the U.S. Federal Motor Vehicle Safety Standards (FMVSS), which a large number of references to the contents of the SAE, ASTM standards, FMVSS 108, ‘Lamps, Reflective Devices, and Auxiliary Devices,’ is one of the items, with a total of 14 chapters, 20 tables, and 20 charts.

Fig 4. Reversing light personal expression.

At the UN level, the Working Group on Lighting and Light Signaling (GRE) of the United Nations Forum for Harmonization of World Vehicle Regulations (UN/WP.29) under the Economic Commission for Europe (ECE) has continued to revise and add to the published regulations on automotive lamps and luminaires every year, and as of March 2019, a total of 35 regulations on automotive lamps and luminaires have been published by UN/WP.29, including vehicle lamps, light sources and retro-reflectors. UN/WP.29 is a mature and complete set of standards for automotive lamps and luminaires, and in March 2012, the EU proposed to consolidate and simplify the regulations for light signaling devices.In 2014, the GRE established a task force, IWG-SLR, to develop three new UN Regulations in the categories of light signaling, road lighting and retro-reflecting devices, and to renumber and consolidate the old Regulations.At the 177th session of the United Nations Forum for the Harmonization of World Vehicle Regulations, held on 12-15 March 2019, the Contracting Parties voted to adopt three new drafts of three new UN Regulations, UN R148 "Light signaling devices", UN R149 "Road lighting devices" and UN R150 "Retro-reflecting devices", three new draft UN Regulations.

At the ISO level, ISO/TC22/SC35/WG1 is primarily responsible for the standardization and revision of standards related to lighting and vision. In this working group, there are five existing standards for automotive lighting, covering flashing devices, special warning lamps and headlamp aiming devices.

3.2 Status of research on standard in China.

China refers to the European UN system for the development of automotive lighting standards, and as of 2024, there are a total of 23 mandatory national standards on the series of lighting and light signaling devices in China, of which 17 are related to automobiles. Along with the integration of European lighting regulations, China also started the integration and revision of the series of mandatory national standards on the series of lighting and light signaling devices in 2017, integrating the original 17 mandatory national standards into 3 mandatory national standards. GB 4599-2024 ‘Road illumination devices and systems for motor vehicles’ corresponds to UN R149 ‘Road Lighting Devices’; GB 5920-2024 ‘Light-signalling devices and systems for motor vehicles and their trailers’ corresponds to UN R148 ‘Light Signaling Devices’; GB 11564- 2024

'Retro-reflective devices and markings for motor vehicles' corresponds to UN R150 'Retro-reflective devices'.

3.3 Standardization Challenges for Automotive Lighting.

3.3.1 Synchronization of technological development and updating of standards

The development of automotive electronics and intelligence has increased the functionality of lamps, and new light sources such as LED and laser have driven the development of technologies such as adaptive headlights. However, technological advances have outpaced standardization, resulting in a lack of clear design and development guidance for companies, which impacts product compliance and market access. In some cases, even when product design is complete, the lack of standards makes it difficult to meet regulatory requirements, resulting in delays to market or limited functionality. In addition, new technologies challenge existing standards and require new standards to ensure compliance and consumer safety, but the delay in updating standards has resulted in new technology products being marketed without appropriate standards, posing risks to both businesses and consumers.

3.3.2 Conflict between diversity of market demands and normative requirements.

The demand for personalization of automotive appearance drives the growth of personalized design of vehicle lighting to enhance aesthetics and meet the pursuit of fashion. Such as ambient lighting, intelligent reversing light light language and other new technologies, although consumers love, but often in the standard gray area. Under the rapid changes in the market, standardization workers need to balance standardization and personalization: to ensure safety and quality. Finding the balance between the two is a major challenge for the standardization of automotive lamps .

4. Standardization of research direction on automotive lighting

The evolution of automotive lamps from a single lighting function to the current state of intelligent lighting has led to their emergence as a pivotal interface between vehicles and the external environment. In light of these developments, standardization efforts must endeavor to address the novel circumstances and requirements that have emerged. This necessitates the integration of standards and technology at an unprecedented level. It is imperative to consider both the functional level of automotive lamps and to propose novel requirements that address the deficiencies in the prevailing standards with regard to new functions. Moreover, it is essential to contemplate the system and vehicle perspectives, taking into account the unique performance characteristics of automotive lamps. This necessitates the formulation of an evaluation method to ensure the system's normal operation.

4.1 Function.

The functionality level is divided into three main areas: **lighting, interaction, and entertainment**

4.1.1 Lighting

The existing standard system has comprehensively addressed all categories of lamps equipped with lighting functions in automobiles, encompassing headlamps (comprising diverse light sources), fog lamps, corner lamps, and daytime running lamps, among others. The system has meticulously delineated performance requirements for these lamps. However, in the face of emerging technologies, such as the application of lighting blankets, the existing standards have fallen short in clearly defining their key performance indicators. These indicators include the starting distance of projection, the shape of the light blanket, width, length, and light uniformity. Consequently, there are evident lacunae in the extant standards for illuminated light carpets that necessitate resolution through future research.

4.1.2 Interaction

Within the domain of vehicle interaction, a taxonomy can be established that delineates between two categories: traditional interaction and new interaction. While both categories are fundamentally designed to transmit status information regarding the vehicle to other vehicles and road users, they differ in their methods of implementation and technical applications. The current standard encompasses traditional interactive luminaires, including turn signals, reversing lights, parking lights, and side marker lights. However, in the face of emerging interactive functionalities, particularly lamp projection technology, adaptive distance lighting (ADB) functions, tail light personalized light language, and other state-of-the-art technologies, the existing standard system exhibits a notable deficiency. For instance, while the GB 4599-2024 standard has relaxed certain restrictions on headlight projection, there remains a paucity of specific requirements for headlight projection symbols, accuracy standards for ADB functions, and response speeds, among other crucial aspects. Consequently, there is an urgent need to undertake systematic standardization efforts for technologies involving new interactive functions in the future, with the aim of addressing the existing standard gaps in this field.

4.1.3 Entertainment

In the realm of vehicle entertainment functions, intelligent headlight technology has undergone a paradigm shift, with the capacity to metamorphose into a high-performance projector. This transformation enables the projection of movies, facilitates outdoor KTV activities, and facilitates a myriad of gaming and entertainment applications. It is noteworthy that standards for this nascent application area remain in a state of flux. However, given that these entertainment functions are designed to be activated when the vehicle is stationary, thereby eliminating any considerations related to safe driving, the adoption of standards to regulate them is not currently necessary. Consequently, it is more pragmatic to align with market demands and adaptively adjust strategies to facilitate the seamless integration of these innovative entertainment features.

4.2 System and vehicle level.

At the system level, the existing standard system places primary emphasis on the light distribution performance of AFS and ADB, along with their respective test methods. However, the current standard has not yet delineated clear provisions concerning the critical accuracy index, response speed characteristics, and the corresponding test process and evaluation methods. Given the pervasive implementation and ongoing advancement of AFS and ADB technologies, it is imperative to address the prevailing lacuna in the regulatory framework of this domain, with the objective of effectively addressing the mounting technical imperatives and the evolving demands of these applications.

At the vehicle level, GB 4785-2019, entitled "Installation Provisions for External Lighting and Light Signaling Devices for Automobiles and Trailers," is the sole national standard that presently stipulates general requirements, special provisions, and inspection rules for the installation of external lighting and light signaling devices for the entire vehicle. However, as vehicle intelligence continues to advance, the lamps system, along with other intelligent vehicle systems, will increasingly operate in a synergistic manner. This will include combinations such as on-board cameras, radar systems, and ADB systems, which will be integrated to enhance their functionality. Consequently, the future standardization efforts must prioritize this direction to establish a more comprehensive, efficient, and intelligent vehicle lighting and signal system standards framework.

5. Summary

This paper provides a comprehensive overview of the historical development of automotive lighting technology. It explores the current status of automotive lighting fixture standardization efforts both domestically and internationally, addressing the challenges encountered during the

technological development process. Additionally, it outlines the current state of research in automotive lighting fixture standard technology in China. In light of the ongoing developments in the industry, it is imperative to continuously enhance the standard system and maintain a steadfast commitment to automotive lighting standard research.

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