



The Application and Development of Modern Welding Technology in the Automotive

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Abstract. As the automotive manufacturing industry moves towards high precision, high efficiency, and intelligence, welding technology plays a crucial role in enhancing the structural strength, manufacturing accuracy, and production efficiency of vehicle bodies. To meet the development demands of intelligent manufacturing, automotive welding technology is gradually evolving towards automation and intelligence. This paper first elaborates on the basic principles and process characteristics of three main welding methods: laser welding, resistance welding, and arc welding. Subsequently, it explores intelligent welding technologies, including the roles of welding robots, machine vision, and various sensor technologies in monitoring and optimizing welding quality. Finally, it analyzes the development process of intelligent technologies in automotive welding and examines the challenges currently faced by intelligent welding technologies. It also envisions and looks forward to the comprehensive application of intelligent technologies such as sensors, automation, artificial intelligence, and robots. This paper aims to systematically review the core technical points and practical application value of intelligent welding technologies in automotive manufacturing, providing theoretical support and optimization ideas for future in-depth research and engineering practice of intelligent welding technologies

Keywords: Automotive Welding; Automation; Artificial Intelligence; Robot; Machine Vision

1 Introduction

In the current era of rapid technological development, the automotive industry is undergoing unprecedented transformation and change. With the increasing scarcity of resources and the intensifying market competition, automotive manufacturing enterprises urgently need to enhance production efficiency, reduce costs, and strengthen the market competitiveness of their products through technological innovation. Welding, as an indispensable key link in the automotive manufacturing process, its technical level directly affects the overall performance and safety of the vehicle. Traditional welding techniques have many limitations in terms of labor costs, welding quality stability, and adaptability to new materials, making it difficult to meet the high

precision, high efficiency, and high quality requirements of modern automotive industry. Against this backdrop, integrating welding technology with cutting-edge intelligent technologies such as sensors, automation, computer algorithms, artificial intelligence, and robotics has become an inevitable choice for the transformation and upgrading of the automotive industry.

The application of intelligent welding technology has brought significant advantages to the automotive manufacturing industry, mainly in terms of cost control, production efficiency improvement, and technical adaptability. Firstly, it can effectively reduce production costs, decrease manpower investment, and lower labor costs. At the same time, it can significantly reduce the defect rate, minimize additional costs due to rework and defective products. Secondly, intelligent welding technology significantly improves the accuracy and speed of welding, optimizes the production process, and enhances overall production efficiency, enabling automobiles to enter the market more quickly and with higher quality [1]. Moreover, intelligent welding technology also has strong adaptability, which can flexibly meet the welding demands of high-strength steel, aluminum alloys and other new materials, and support the application of new processes such as laser welding, providing a broader development space for automotive manufacturing enterprises and helping them gain an advantage in the fierce market competition.

This article conducts an in-depth exploration of welding technology, particularly the application status of intelligent welding technology in the automotive field. It analyzes the unique advantages and challenges it has demonstrated in the automotive manufacturing process, and looks forward to the future development trends. The aim is to provide beneficial references and inspirations for the further development of automotive welding technology, and to promote the high-quality and sustainable development of the automotive industry with the assistance of intelligent welding technology.

2 Automotive Welding Methods

In the automotive manufacturing field, welding technology is the core process that guarantees the structural strength, manufacturing accuracy and production efficiency of the vehicle body. The most common three welding methods are laser welding, resistance welding and arc welding. These three welding techniques form the basis of intelligent automotive welding and have achieved remarkable progress in recent years.

2.1 Laser Welding

Laser welding utilizes a high-energy-density laser beam as the heat source for welding, achieving better welding accuracy and higher efficiency. It is mainly applied in the precise welding of micro and small-sized parts. For instance, due to the high requirements for welding quality, automotive transmission gears first adopted the laser welding process. The weight, rotational speed, frictional force, etc. during operation all need to be taken into account. Moreover, in automotive welding, it is challenging to use traditional welding techniques to weld copper onto itself and other metals. The process

window for welding copper using infrared (IR) lasers is very narrow. For infrared lasers, the high reflectivity of these wavelengths makes it difficult to couple power into the material and control the temperature of the molten pool. In the case of ultrasonic and resistance welding, the high thermal conductivity of the materials and the tendency to generate particles can lead to suboptimal welds. These fundamental problems can be overcome by using lasers with wavelengths that are highly absorbed by these materials. High absorption means that the power required to start the welding process is lower than that of infrared lasers. In automotive body welding, when welding copper and other dissimilar metals onto steel, compared with infrared lasers, this laser can deposit more energy in copper; thus, better welding of copper to steel or copper to aluminum can be achieved [2]. Therefore, this method not only effectively improves the quality and efficiency of body welding but also enhances the material utilization in the vehicle manufacturing process, significantly improving the product quality of vehicle manufacturing.

2.2 Resistance Welding

Resistance welding, also known as resistance spot welding, is one of the most widely used welding methods in automotive production. Its core principle is to utilize the heat generated by the current passing through the weldment to melt the metal, thereby achieving welding. It is mainly used for welding thin sheet components such as body assemblies, floor, doors, side panels, rear panels, etc. For example, resistance welding is also commonly used for welding parts such as body floor, doors, engine hood covers, and trunk covers [3]. Resistance welding has the characteristics of high efficiency and rapidity, which can significantly improve the production efficiency of automotive production lines. At the same time, resistance welding can achieve high-strength connections, ensuring the stability and safety of automotive components. Moreover, resistance welding can also be precisely controlled through automated equipment to ensure welding quality.

2.3 Arc Welding Welding

Arc welding is also widely applied in the automotive manufacturing field. This method utilizes the high temperature generated by the arc to melt the metal and protects it with inert gases and rare gases to prevent the molten pool from being oxidized and contaminated by air, thereby achieving high-quality welding. Arc welding has the characteristics of high efficiency, flexibility, and wide applicability, and is widely used in multiple fields, especially in the welding of vehicle bodies and components, playing an important role in further improving welding efficiency. In the automotive manufacturing process, load-bearing structural components such as chassis crossbeams, longitudinal beams, and suspension systems that bear high loads require high-strength welding to ensure the structural strength and safety of the vehicle. Such welding operations usually adopt gas shielded welding (GMAW) or submerged arc welding (SAW) [4], and these technologies can provide sufficient stamping and

welding strength to meet the high-strength, durability, and safety requirements of automotive manufacturing.

3 Intelligent Automobile Welding

With the development of intelligent manufacturing, automotive welding is moving towards high-level automation and intelligence. Among them, the wide application of welding robots is the core of intelligent welding, which greatly improves the accuracy and efficiency of welding. On this basis, the intelligent welding system further integrates machine vision technology for weld seam recognition, trajectory tracking and defect detection. At the same time, it combines temperature, pressure and other sensor technologies to achieve real-time monitoring and quality optimization of the welding process. The collaborative application of these intelligent technologies makes automotive welding more precise and efficient, and promotes the development of automotive manufacturing towards a more intelligent direction.

3.1 Welding Robot

The most prominent feature of automotive welding automation is the application of welding robots. Welding robots, equipped with precise control systems and highly sensitive mechanical arms, can complete single repetitive but complex and precise welding tasks within a short period of time. For instance, in body welding, welding robots can perform welding according to preset programs and trajectories, ensuring the accuracy and consistency of the welding positions, and significantly improving the quality and efficiency of welding. Another example is the welding of automotive studs, which requires stud welding robots. Technicians input relevant parameters such as stud welding point coordinates and welding trajectories into the control system to quickly achieve precise positioning and confirm the stud welding positions, thereby achieving welding diversity and improving welding accuracy and efficiency [5]. Meanwhile, modern welding robots combine advanced sensors and image processing technologies to enable adaptive adjustment of welding parameters and path planning. For instance, intelligent welding robots can monitor parameter changes in the welding process in real time through sensors and automatically adjust welding strategies. This intelligent and flexible feature enables robots to adapt to the needs of different vehicle models and complex working conditions.

3.2 Machine Vision Technology

In automotive body welding, arc welding operations on automotive frame sheet metal parts are quite common. It is necessary to detect and discriminate the weld bead length, width, position, and welding defects of the workpiece. The use of a visual system not only enables the detection of the geometric dimensions of the weld seam, but also can identify common welding defects such as cracks, incomplete fusion, and porosity. By comparing with standard images, the system can quickly generate defect reports,

providing data support for subsequent maintenance and improvement. After the detection is completed, the detection data and discrimination results are displayed. Moreover, during the welding process, thermal stress may cause deformation of the welded parts. The machine vision system can quickly and accurately detect the deformation of the welded parts by measuring and analyzing the overall or local images of the welded parts. This provides important basis for subsequent correction and compensation, ensuring the dimensional accuracy of the welded parts [6]. Conducting on-site detection using vision not only strictly controls product quality but also can promptly adjust welding process parameters and welding gun trajectories based on the detection results to ensure the normal operation of the production cycle.

Machine vision focuses on the self-discrimination of machine vision systems. For instance, in the recognition and tracking of weld seams, machine vision systems capture real-time images of the welding area through high-resolution cameras or 3D sensors. They can accurately identify the position, shape and size of the weld seams. Combined with the planning of welding paths, robots can precisely track along the weld seams, maintaining stable welding quality even in the presence of complex curved surfaces or slight deviations of the workpiece [7].

3.3 Other Sensor Technologies

Other sensors are also used in automotive welding. For instance, temperature sensors can monitor the temperature changes during the welding process in real time, ensuring that the welding temperature remains within the appropriate range and avoiding any impact on the welding quality due to excessive or insufficient temperature. Moreover, in laser welding, sensors can monitor real-time information such as the thickness, material, and welding position of the vehicle body sheet, automatically adjusting the laser power and welding speed. In terms of automotive welding quality inspection, sensors can detect welding defects such as cracks, incomplete fusion, and pores [8]. Combined with image processing and data analysis technologies, sensors can quickly identify defects and provide feedback, enabling the system to automatically correct and for manual intervention. This technology not only improves the inspection efficiency but also effectively reduces the rework costs caused by welding defects, further enhancing the production efficiency and welding quality of automotive manufacturing.

4 The Development Process of Intelligent Technology in Automotive Welding

4.1 Application of Artificial Intelligence

The development and application of artificial intelligence technology have propelled automotive welding into a fast-track of progress, and it is also an important indicator marking the advancement from the third technological revolution to the fourth. Artificial intelligence can be widely applied to all aspects of automotive welding from production to inspection, especially in the detection control of the welding process and the assessment of welding quality. In terms of the quality inspection of welding results,

the combination of deep learning and machine vision technology can analyze the images and data generated during the welding process, enabling immediate assessment of weld seam quality and detection of potential defects, thereby significantly enhancing the efficiency and reliability of welding operations. For instance, AI-driven machine vision systems can monitor the shape, position, and quality of weld seams in real time during the welding process. Through deep learning algorithms, the system can automatically identify defects in weld seams, such as pores, cracks, and incomplete fusion areas, and promptly adjust welding parameters [9]. For example, Dongfeng Passenger Vehicle Factory utilized its independently developed "Zhu Rong" large model to achieve real-time detection and optimization of weld point quality, significantly improving welding quality and production efficiency. Meanwhile, through machine learning algorithms, AI can analyze a large amount of welding data and identify patterns and trends related to welding parameters. These data include current, voltage, welding speed, and material type, etc. AI models can predict the optimal welding parameter configuration based on big data combined with established algorithms to achieve the best welding quality and efficiency.

4.2 Current Limitations and Future Prospects

Although intelligent welding has brought many advantages to automotive manufacturing, it still faces a series of challenges in practical applications. Firstly, the materials used in automotive manufacturing are increasingly diverse, including high-strength steel, aluminum alloys, and composite materials, etc. Traditional welding processes have insufficient adaptability to these new materials. Moreover, intelligent welding equipment needs to be customized for different materials and structures, which increases technical difficulty. Tasks that can be stably handled by manual processing can often be handled by intelligent welding, which requires comprehensive processing of data on welding materials and welding surfaces before welding. Although it has a beneficial effect on repetitive welding tasks with universal applicability, its efficiency is much lower than manual operation for special and single welding tasks. Additionally, during the intelligent welding process, real-time monitoring and adjustment of welding parameters can improve quality, but complex welding environments and variable workpiece characteristics may still lead to quality problems. Finally, with the development of intelligent welding, the external environment that welding needs to face is also becoming increasingly complex. Maintaining the accuracy of sensors and other data collection tools in various complex environments has also become an unavoidable issue.

With the continuous development of artificial intelligence technology, the degree of automation in automotive welding will gradually deepen, and welding robots will develop in a more intelligent direction. They will gradually transform from the original manual programming systems to autonomous learning by robots and adapt to different welding tasks. Unmanned welding workshops will become the future development trend. Through advanced sensor technology, automation control technology and artificial intelligence technology, unmanned operation in welding workshops can be achieved [10]. This will greatly improve production efficiency, reduce labor intensity,

enhance product quality, and also ensure construction safety. At the same time, intelligent welding will be deeply integrated with emerging technologies such as big data, Internet of Things, and machine learning. Through Internet of Things technology, welding equipment can achieve remote monitoring and predictive maintenance, and problems can be discovered and solved in advance. Big data analysis can optimize welding process parameters and improve the stability of welding quality.

5 Conclusions

The application of intelligent welding technology in the automotive industry has become an important force driving the high-quality development of the automotive manufacturing sector. This article systematically elaborates on the advantages of intelligent welding technology in automotive production, including cost savings, efficiency improvement, and adaptability to new materials and processes. The analysis of three main welding methods - laser welding, resistance welding, and arc welding, demonstrates their significant roles and unique advantages in automotive manufacturing. At the same time, the combination of intelligent technology and welding, especially the application of welding robots, machine vision, and other sensor technologies, has greatly enhanced the accuracy, efficiency, and quality stability of welding. Although intelligent welding technology has made remarkable progress in automotive manufacturing, it still faces some challenges, such as insufficient adaptability to new materials, problems with sensor accuracy in complex environments, and efficiency bottlenecks for special welding tasks. However, with the continuous development of emerging technologies such as artificial intelligence, big data, and the Internet of Things, future automotive welding is expected to achieve a higher degree of automation and intelligence. Unmanned welding workshops will become possible, and welding robots will possess stronger autonomous learning and adaptability capabilities, thereby further improving production efficiency, reducing labor intensity, and ensuring construction safety.

Therefore, the application prospects of intelligent welding technology in the automotive industry are extremely broad. Through continuous technological innovation and interdisciplinary integration, this technology is expected to bring greater breakthroughs and development to the automotive manufacturing industry in the future, and provide strong support for the transformation and upgrading of the automotive industry.

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