



## STUDY OF AUTOMATION OF TEMPERATURE MEASUREMENT AT THE WORKING POINT IN LASER COATING

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### ABSTRACT

In modern production technologies, various methods are used to strengthen the surface and increase its operational qualities. Among these methods, the laser cladding process has been distinguished in recent years by its superiority and wide application area.

Laser cladding is a process of melting and solidifying an additional material on the surface of the base metal with the help of a high-energy laser beam. As a result, a coating layer with high wear, corrosion and temperature resistance is formed. In this process, the temperature regime of both the material to be coated and the base surface plays a decisive role, since temperature instability directly affects the quality of the coating.

Thermal processes occurring during laser cladding are very fast and complex. Therefore, real-time monitoring and control of the process is necessary.

Accurate and continuous temperature measurement is of great importance in ensuring the homogeneity, microstructure, adhesion and resistance to cracking of the coating. Traditional measurement methods have difficulty responding to this fast and dynamic process. Therefore, the application of automated and highly sensitive sensor systems has become a necessity.

As a result of technological developments, non-contact measuring devices such as pyrometers, thermal cameras and infrared sensors are integrated into laser coating systems. These devices make it possible to measure temperature in real time and transmit the results to the controllers that control the process. Control systems (for example, PID algorithms or artificial intelligence-based models) can analyze this data and automatically adjust the laser power, coating speed and other parameters. The purpose of this research work is to investigate methods for automating temperature measurement at the working point (i.e. in the zone where the laser beam comes into contact with the surface) in the laser coating process, to analyze applicable technologies and equipment and to evaluate the factors affecting the efficiency of the process. Automation and digitalization measures to be implemented in this direction in the future can accelerate the transition of the industry to more sustainable, economical and high-quality product production.

The object of the research: technical means and systems used to measure temperature at the working point (the zone affected by the laser) in the laser coating process and to automate this measurement. This includes temperature measurement sensors (pyrometers, thermal cameras, and other infrared devices), control modules used for data collection and processing (microcontrollers, PLC systems), as well as software and control algorithms that provide communication between these components. Thanks to the application of the proposed automated system, temperature deviations were reduced from  $\pm 50^{\circ}\text{C}$  to  $\pm 15^{\circ}\text{C}$ , the microstructural stability of the product surface was maintained, and the need for human intervention in the control process was significantly reduced.

It is recommended that future research continue to make control more flexible, predictable, and safe through the application of artificial intelligence-based control algorithms, smart sensor technologies, and cloud-based SCADA systems.

**Keywords:** laser, laser coating, laser temperature, measurement, automation.



## **Introduction**

Coating processes are a type of industrial service that involves the use of specialized equipment and techniques to join metal components or apply a protective coating to a metal surface. These services are commonly used in industries such as manufacturing, construction, and transportation where the integrity and durability of metal components are essential.

Welding services involve the use of heat and pressure to join two or more pieces of metal. Welding can be used to create strong and durable joints in metal components such as pipes, beams, and plates. There are several types of welding processes, including arc welding, gas welding, and resistance spot welding, each of which is suitable for different types of metals and applications.

There are a number of different coating processes available, depending on the industry and application. The coating process has a number of advantages and disadvantages, depending on the type of coating used [1,2].

The history of coating processes can be traced back thousands of years to ancient civilizations such as the Egyptians, Greeks, and Romans, who used heat and pressure to make weapons, tools, and decorative objects from metals. Laser coating of metal surfaces is a unique and most effective method of depositing wear-resistant coatings. It is carried out using new generation laser systems, the operation of which is based on the use of a powerful fiber optic laser and a special nozzle. A high-power laser beam is directed onto the surface of the part and creates a small molten pool. Metal powder is fed to this area, which, when melted, forms a new layer. A robotic arm that prepares the surface according to a pre-written program ensures the highest accuracy and speed of the process. Thermal deformation and mixing with the base material are minimized due to the strictly limited heating area and controlled power of the laser beam. The result is a completely dense hard coating layer with excellent metallurgical adhesion, which cannot be achieved by other coating methods (chromium plating, thermal spraying, etc.).

## **Objective**

The aim of this research work is to investigate methods for automating temperature measurement at the working point (i.e., in the area of contact between the laser beam and the surface) during the laser coating process, to analyze the technology and equipment used, and to evaluate the factors affecting the efficiency of the process. The object of the study: technical means and systems used to measure the temperature at the working point (in the laser exposure zone) during the laser coating process and the automation of this measurement. These include temperature measurement sensors (pyrometers, thermal imagers, and other infrared devices), control modules used for data collection and processing (microcontrollers, PLC systems), as well as software and control algorithms that provide communication between these components.

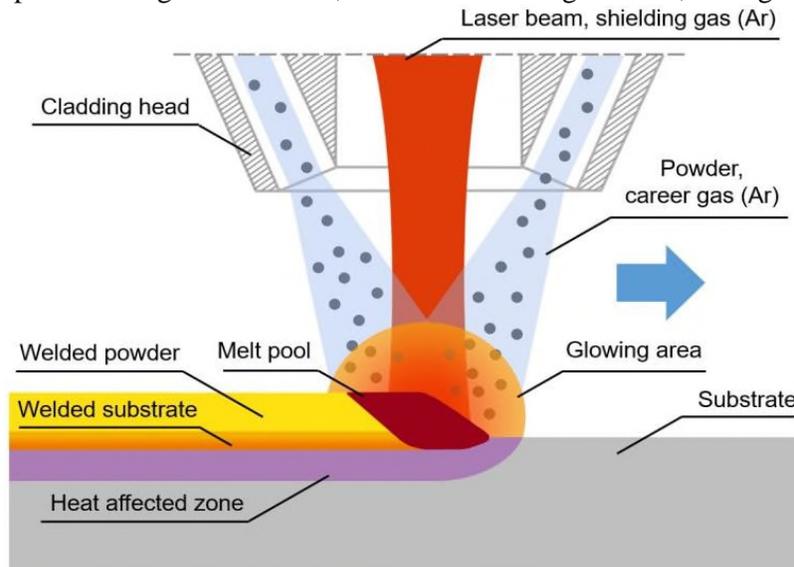
## **Methods**

Laser coating is a modern industrial coating method that makes it possible to improve the properties of various parts of machinery and equipment, such as resistance to wear, corrosion and high temperatures. In laser cladding, a filler material is applied to the surface of the workpiece, which is fused to the surface of the base material using a laser beam. Under the influence of the laser beam, a small part of the surface of the base material also melts, thus forming a stable molten bond between the filler and the base material (Figure 1).

Laser cladding achieves excellent density and low mixing of the base material and the coating. Typical coating thicknesses are in the range of 0.5-3 mm. A small heat input causes very little change in the base material. Laser cladding is suitable for most coating-to-base material joints.

Examples of damage to be repaired: worn edges, creases, broken molds; wear of gear seats, bearings on shafts, teeth of threaded fasteners, etc.; wear of stepped shaft surfaces (including keyways); wear of exhaust and intake valves, valve spools; breakage, cracking of the mold wall for molding rubber

or plastic; defects in the blades of gas turbine engines - wear of the body and base of the blade, crushing and chips on the edge of the blade; wear of turbocharger rotors; damage to parts made of



**Figure 1.** Laser coating process

high-strength alloys operating under shock-abrasive and shock loads (drilling tools, punching dies, etc.); wear and defects of large-sized products weighing up to several tons; and others.

During single-stage coating, the coating material is applied to the parts simultaneously with a laser beam. Single-stage coating is an example of a process with a single-beam spray gun. Usually, the laser beam is directed vertically onto the base material. In this case, the coating material is directed at the laser beam at a certain angle (usually 45-55 degrees) to the place where the laser hits. Part of the laser beam causes a certain melting of the coating material, and part of it causes melting of the base material. At this time, the movement of the part (head) causes the mixing and solidification of the molten coating and the base material.

For the process to be correct, the energy of the laser beam must be adjusted to the amount of coating material and the movement of the part in the right way. In this case, the following cases are possible. The speed and amount of material are kept constant, the laser energy is changed. In this case, when the energy is reduced and increased, the mixing zone between the coating material and the base material will change proportionally.

The speed of the process changes at a constant rate of the laser beam and the amount of coating. In this case, the thickness of the mixing zone will be inversely proportional. It should be noted that in this case there will be a change in the thickness of the coating. The laser and the process speed are inversely proportional when the amount of fixed powder is variable. [4,3]

In single-beam sprayers, the sprayers are attached to the laser head at an angle of 45-55 degrees. The distance between the place where the sprayer sprays the material and the place where the process takes place is approximately 10 mm. Before starting the process, the spray material sprayed by the laser beam must be adjusted. According to current requirements, the method of applying coatings with continuous laser action has a number of undeniable advantages: ensuring the adhesion strength of the base and filler metal; low residual stresses and deformation; ensuring the process with a minimum penetration depth of the base; increasing the utilization factor of the deposited material. In this work, the laser coating process was carried out in a robotic laser complex based on a high-power multimode continuous wave ytterbium fiber laser LS-2. The surface coating was applied by a coaxial method, with self-flow of PR-20Kh13N2: PR-NH17SR3 powder in a ratio of

3:1 in a protective gas environment. The appearance, characteristics and operating parameters of the laser coating complex are clearly shown in Figure 2.



**Figure 2.** View of the laser coating complex

Gas welding is a metal joining process that involves melting metals using fuel gases such as acetylene, propane or hydrogen mixed with oxygen to create a weld. This type of welding is commonly known as "Oxy-Acetylene Welding" because oxygen and acetylene are the most commonly used gases in this type.

Gas welding, also known as oxy-fuel welding or oxyacetylene welding, is a heat-based process used to cut and join metals. It involves the combustion of fuel gases such as acetylene or gasoline with oxygen to create heat that melts and joins the ends of the metals. The process can be performed using a variety of gas combinations, but the most common are oxygen and acetylene. A practical example of this type is illustrated in Figure 3 below.



**Figure 3.** Gas welding with oxygen and acetylene

Pyrometers are divided into two types based on temperature measurement technology: optical pyrometers and infrared pyrometers [5,6]. Each type has specific uses and advantages, so the choice of pyrometer allows for accurate, efficient temperature readings. Infrared (IR) pyrometers: non-contact, high-speed measurement - These devices are ideal for non-contact and real-time temperature measurement, especially in high-temperature and dynamic processes such as laser coating. IR pyrometers determine the temperature of an object by measuring the thermal radiation (infrared waves) emitted from its surface. This device uses Planck's law or Stefan-Boltzmann's law to calculate the temperature without physical contact with the object. The basic principle is that hot objects emit more infrared radiation → the sensor receives this radiation → the internal electronics calculate the temperature. Optical pyrometers use traditional optical temperature measurement technology. They work by observing the spectrum of light emitted by an object. These devices contain sophisticated optical lenses and spectrum analyzers to capture and analyze the light. During operation, the operator points the pyrometer at the target object. The device then detects changes in brightness and color in the object's emission spectrum, which increase as the temperature increases.



These changes are analyzed to determine the object's temperature. Optical pyrometers work well in environments that are not affected by ambient light, making them ideal for bright temperature measurements in high temperatures, high radiation, or bright environments, such as steel or glass furnaces.

Different quenching temperatures for hypoeutectoid and hypereutectoid steels are due to the fact that ferrite is present in the structure of hypoeutectoid steels below the GS line, and if quenching is carried out from this area, austenite will turn into martensite, and ferrite will remain in ferrite structure as it is. Since ferrite is soft, it significantly reduces the hardness of the hardened steel. Based on this, hypoeutectoid steels need to be heated above the GS line (i.e., above the Ac3 point). In hypereutectoid steels, when heated above the PSK line (i.e., above the AC1 point), there is no ferrite, therefore, there is no need to heat these steels above (above the SE line), because A and C are present in this area. A - when cooled, turns into martensite, and there will also be a solid component - cementite in the structure. To determine the cooling conditions during hardening of steel, it is first necessary to take into account the regularities of the transformation of austenite into other structures at different cooling rates. The C-shaped diagram gives an idea of this.

When quenching steel, they usually try to obtain martensite in the steel structure. Therefore, knowing the features of the formation of the structure during cooling of austenites at different speeds, it is possible to determine the conditions for cooling the steel according to the C-shaped diagram to obtain a martensite structure. The minimum cooling rate at which austenite cools to the Mn point and then turns into martensite is the tangent to the C-shaped curve. This cooling rate is called critical. Thus, the cooling rate during quenching must be higher than critical. For ordinary carbon steels, this is about 150 m / s.

This speed is achieved by cooling in water or aqueous solutions of salts.

Since quenching for martensite occurs only at a cooling rate higher than critical, with a sufficiently large thickness of the part, it may turn out that the cooling rate in the core will be less than critical. In this case, only a certain surface layer will be solidified on martensite, while the core will remain unhardened, have a different structure and other properties.

When hardening real parts, it is necessary to know when hardening is possible over the entire section or how deep the hardened layer will be. The criterion for such an assessment is the hardenability of the steel, which is understood as the depth of the hardened layer.[7,8]

The results of the study showed that accurate and real-time measurement of the temperature at the working point during the laser coating process is one of the main factors in ensuring the physical and mechanical quality of the coating. Maintaining the temperature at an optimal level during the process minimizes structural changes and thermal deformations on the material surface, creating conditions for obtaining a homogeneous and durable coating.

## Conclusion

The non-contact infrared pyrometers used in the study allowed for high-speed and accurate measurement of the temperature at the working point during laser coating. The temperature fluctuation was monitored in real time through an automated measurement system, and when it reached a critical level, the system was able to dynamically self-regulate by intervening in the process parameters (adjusting the laser power, changing the scan speed, etc.).

The following main results were obtained based on the study:

1. Automatic temperature measurement directly affects the quality of the coating:
  - Maintaining the optimal temperature range improved the adhesion and micromorphology of the coating.
  - Sudden increases or decreases in temperature have created cracks, pores, and unevenness in the coating.

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## LAZERLƏ ÖRTÜK ÇƏKMƏDƏ İŞ NÖQTƏSİNDƏKİ TEMPERATURUN ÖLÇÜLMƏSİNİN AVTOMATLAŞDIRILMASININ TƏDQIQI

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### XÜLASƏ

Müasir istehsal texnologiyalarında səthi gücləndirmək və əməliyyat keyfiyyətlərini artırmaq üçün müxtəlif üsullardan istifadə olunur. Bu üsullar arasında lazerlə üzlənmə prosesi son illərdə öz üstünlüyü və geniş tətbiq sahəsi ilə seçilir. Lazer örtüyü zamanı baş verən istilik prosesləri çox sürətli və mürəkkəbdir. Buna görə də prosesin real vaxt rejimində monitorinqi və nəzarəti zəruridir. Temperaturun dəqiq və davamlı ölçülməsi örtüyün homojenliyinin, mikrostrukturunun, yarıqşmasının və çatlamaya davamlılığının təmin edilməsində böyük əhəmiyyət kəsb edir. Texnoloji inkişafın nəticəsində pirometrlər, termal kameralar və infraqırmızı sensorlar kimi təməssiz ölçmə cihazları lazer örtük sistemlərinə inteqrasiya olunur. Bu tədqiqat işinin məqsədi lazer örtük prosesində iş nöqtəsində (yəni lazer şüasının səthlə təmasda olduğu zonada) temperaturun ölçülməsinin avtomatlaşdırılması üsullarını araşdırmaq, tətbiq olunan texnologiya və avadanlıqları təhlil etmək və prosesin səmərəliliyinə təsir edən amilləri qiymətləndirməkdir. Tədqiqatın obyektini: lazerlə örtülmə prosesində iş nöqtəsində (lazerin təsir etdiyi zonada) temperaturun ölçülməsi və bu ölçmənin avtomatlaşdırılması üçün istifadə olunan texniki vasitələr və sistemlər. Buraya temperatur ölçmə sensorları (pirometrlər, istilik kameraları və digər infraqırmızı cihazlar), məlumatların toplanması və emalı üçün istifadə olunan idarəetmə modulları (mikrokontrollerlər, PLC sistemləri), həmçinin bu komponentlər arasında əlaqəni təmin edən proqram təminatı və idarəetmə alqoritmləri daxildir. Gələcək tədqiqatların süni intellektə əsaslanan idarəetmə alqoritmləri, ağıllı sensor texnologiyaları və bulud əsaslı SCADA sistemlərinin tətbiqi vasitəsilə nəzarəti daha çevik, proqnozlaşdırıla bilən və təhlükəsiz etmək üçün davam etdirilməsi tövsiyə olunur.

Açar sözlər: lazer, lazer örtük, lazer temperaturu, ölçmə, avtomatlaşdırma.



## ИССЛЕДОВАНИЕ АВТОМАТИЗАЦИИ ИЗМЕРЕНИЯ ТЕМПЕРАТУРЫ В РАБОЧЕЙ ТОЧКЕ ПРИ ЛАЗЕРНОМ НАНЕСЕНИИ ПОКРЫТИЙ

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### РЕЗЮМЕ

Тепловые процессы, происходящие при лазерной наплавке, очень быстрые и сложные. Поэтому необходим мониторинг и контроль процесса в режиме реального времени. Поэтому применение автоматизированных и высокочувствительных сенсорных систем стало необходимостью. Целью данной научно-исследовательской работы является исследование методов автоматизации измерения температуры в рабочей точке (т.е. в зоне контакта лазерного луча с поверхностью) в процессе лазерного нанесения покрытий, анализ применяемой технологии и оборудования, а также оценка факторов, влияющих на эффективность процесса. Объект исследования: технические средства и системы, используемые для измерения температуры в рабочей точке (в зоне воздействия лазера) в процессе лазерного нанесения покрытий и автоматизации этого измерения. К ним относятся датчики измерения температуры (пирометры, тепловизоры и другие инфракрасные приборы), модули управления, используемые для сбора и обработки данных (микроконтроллеры, системы ПЛК), а также программное обеспечение и алгоритмы управления, обеспечивающие связь между этими компонентами. Благодаря внедрению предлагаемой автоматизированной системы отклонения температуры удалось сократить с  $\pm 50^{\circ}\text{C}$  до  $\pm 15^{\circ}\text{C}$ , сохранить микроструктурную стабильность поверхности изделий, а также существенно снизить необходимость вмешательства человека в процесс управления. Рекомендуется продолжить дальнейшие исследования, чтобы сделать управление более гибким, предсказуемым и безопасным за счет применения алгоритмов управления на основе искусственного интеллекта, технологий интеллектуальных датчиков и облачных систем SCADA.

**Ключевые слова:** лазер, лазерное покрытие, температура лазера, измерение, автоматизация.

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