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Problems of weld overlay of seating surfaces of pipe fitting and solutions***

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Проблемы наплавки уплотнительных поверхностей трубопроводной арматуры и пути их решения*

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Introduction. A problem of providing the necessary functions of pipe fitting for blockage, control, distribution of the working medium flows under the most adverse operating conditions of oil and gas pipelines associated with abrasive particles, mechanical impurities, hydrogen sulfide, carbon dioxide and organic acids with sulfate-reducing bacteria, is considered.

Materials and Methods. High performance properties of seating surfaces of pipe fittings are provided through anticorrosive plating of alloyed and high-alloyed metals based on iron with the addition of chromium, nickel, cobalt and niobium. The basic weld overlay methods are analyzed: metal-arc welding, nonconsumable and consumable-electrode weld facing in shielding gases, submerged arc surfacing. Advantages and disadvantages of surfacing methods implemented in recent years are noted: laser, plasma-powder and plasma-arc methods.

Research Results. Taking into account the automation capabilities, a high-tech process of robotic anticorrosive surfacing using a consumable electrode with an additional filler metal feed to the front welding puddle for shielding the thermal effect of the arc, is proposed. Industrial application of the proposed technology requires a set of studies related to assessing the effect of technological parameters on the quality of the deposited layers to provide the required operational characteristics of the fitting.

Discussion and Conclusion. It is proposed to carry out the above studies using physical and mathematical modeling of the anticorrosive surfacing, which reduces the time and number of experiments. Therefore, the primary task is to develop a mathematical model of the surfacing process with a consumable electrode with an additional filler wire and transverse vibrations of the welding burner. Such a model

Введение. Рассматривается проблема обеспечения необходимых функций трубопроводной арматуры по перекрытию, регулированию, распределению потоков рабочей среды в крайне неблагоприятных условиях эксплуатации нефтегазовых трубопроводов, связанных с наличием в углеводном сырье абразивных частиц, механических примесей, сероводорода, углекислого газа и органических кислот с сульфато-восстанавливающими бактериями.

Материалы и методы. Высокие эксплуатационные свойства уплотнительных поверхностей трубопроводной арматуры обеспечивает антикоррозионная наплавка легированных и высоколегированных металлов на основе железа с добавлением хрома, никеля, кобальта и ниобия. Проанализированы основные методы наплавки: дуговой наплавки покрытыми электродами, неплавящимся и плавящимся электродами в защитных газах, дуговой наплавки под флюсом. Отмечены преимущества и недостатки реализуемых в последние годы способов наплавки: лазерной, плазменно-порошковой и плазменно-дуговой.

Результаты исследования. С учетом возможностей автоматизации предложен высокотехнологичный процесс роботизированной антикоррозионной наплавки плавящимся электродом с подачей дополнительной присадочной проволоки в переднюю часть сварочной ванны для экранирования теплового воздействия дуги. Промышленное применение предлагаемой технологии требует проведения комплекса исследований, связанных с оценкой влияния технологических параметров на качество наплавляемых слоев для обеспечения требуемых эксплуатационных характеристик арматуры.

Обсуждение и заключение. Вышеуказанные исследования предложено выполнять с применением физико-математического моделирования процесса антикоррозионной наплавки, сокращающего время и количество экспериментов. Поэтому первоочередной задачей является разработка математической модели процесса наплавки плавящимся электродом с дополнительной присадочной проволокой и поперечными колебаниями наплавочной горелки. Такая модель должна

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should virtually reproduce the surfacing process, as well as its thermal cycle followed by calculating the ratio of the structural components of the deposited metal and the substrate metal. The system of equations of the model should be solved by a special computer program. The algorithm presented for solving this class of problems will allow us to make a sound connection of the technological parameters of the surfacing process and the quality parameters of the formation of the deposited layers, to determine the program for their optimization to provide the required operational properties of pipeline fitting.

виртуально воспроизводить процесс наплавки, а также его термический цикл с последующим расчетом соотношения структурных составляющих наплавленного металла и металла подложки. Система уравнений модели должна решаться специальной компьютерной программой. Представленный алгоритм решения данного класса задач позволит установить четкую взаимосвязь между технологическими параметрами процесса наплавки и показателями качества формирования наплавляемых слоев, определить программу их оптимизации для обеспечения требуемых эксплуатационных свойств трубопроводной арматуры.

Keywords: anticorrosive surfacing, stop valve, pipeline fitting, mathematical model of surfacing, consumable electrode, filler wire.

Ключевые слова: антикоррозионная наплавка, затворный узел, трубопроводная арматура, математическая модель наплавки, плавящийся электрод, присадочная проволока.

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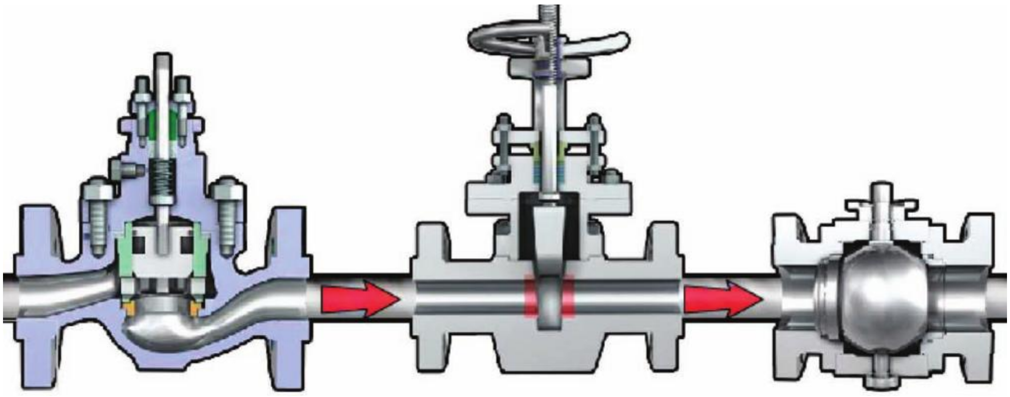
Introduction. Russia has not only the largest resource base, but also huge experience in the creation and operation of its infrastructure. The most important infrastructure element is an extensive network of pipelines for transporting oil, gas and their products since oil and gas fields in Russia and their consumers are geographically spaced over vast distances [1]. This requires solving a number of tasks, the first of which is management of the delivery of hydrocarbons to consumers. However, operational dispatch control of the flow of raw materials in pipelines is impossible without appropriate fittings. The essential shutoff and control functions of oil-and-gas valves are provided by its stop valve, which, depending on its application, creates conditions for shutting off, regulating, distributing the working medium flow through changing its flow area.

According to the technique of stopping the flow and the design features of the stop valves, all types of pipeline valves are classified into valves, gate valves and ball valves. Their structural differences (Fig. 1) are clearly shown in [2]. Valve assembly, as a rule, consists of two contact elements - a seat and a flapper.



a) *b)* *c)*

Fig. 1. Design features of stop valves of pipeline equipment: *a*) throttle; *b*) flapper; *c*) ball valve [2]

In throttles (Fig. 1, *a*), the flapper moves along the medium flow; in gate valves (Fig. 1, *b*), the flapper moves perpendicular to the work medium flow; in taps, the blocking element rotates around the axis of the device perpendicular to the medium flow. Depending on the revolutional shape, valves are conical, cylindrical and ball. The operation diagram of ball valves is shown in Fig. 1, *c*. As a rule, the seal in the gate is carried out according to the "metal-metal" scheme. Notice that ball valves are the ones that provide the minimum resistance to flow in the open position, have a higher opening/closing speed, and a longer uptime [3].

The transportation of crude hydrocarbons is characterized by high pressures both in the pipelines and in the pipe fittings. In addition, the production and processing of hydrocarbons is invariably associated with the transportation of raw materials containing abrasive particles and solids through pipeline systems. The transported medium may also contain hydrogen sulphide (H_2S) and carbon dioxide (CO_2). Besides, during the transportation of crude oil, condensate, containing organic acids and sulphate-reducing bacteria, may form on the contact surfaces of the valve. Currently, the gas liquefaction industry is rapidly developing, where all processes occur at extremely low temperatures. Low temperatures also create certain problems when operating valves.

Materials and Methods. Considering the listed operating conditions, the design of the stop valve should exclude jamming of the valves and provide their resistance to corrosion and hydroabrasive wear. Often, such requirements are provided by surfacing with wear- and corrosion-resistant materials. However, many problems of import substitution of such products are restrained due to the unresolved issues regarding the implementation of surfacing processes. This actualizes the need for improving technologies for anticorrosive surfacing of sealing surfaces of pipeline valves.

It is known that body parts and the stop valve components of the pipeline valve are made of unalloyed, alloyed and high alloyed steels, the blanks for which are obtained through rolling, casting or stamping [4]. The initial data determining the selection of specific materials for the reinforcement are the conditions under which it will be operated. Important is the change in the properties of the metal during long-term operation. It should be noted that in the manufacture of parts and assemblies of pipe fittings, cheaper unalloyed steels are often used, and the required anticorrosive properties of the sealing surfaces are provided through surfacing of alloyed and high alloyed metals. Therefore, surfacing is currently a priority in providing the required operational properties of sealing surfaces of valves. Depending on the operating conditions of the fittings, iron-based surfacing materials with the addition of chromium, nickel, cobalt and niobium are used.

Since the main requirement for corrosion-resistant surfacing is its resistance to hydrogen sulphide cracking and carbon dioxide corrosion, this requirement is met through a reasonable selection of materials, surfacing techniques and their modes. Currently, when surfacing pipe fittings, metal-arc welding, non-consumable surfacing with filler wire, mechanized welding in shielding gases and submerged arc surfacing are most common [5]. The listed surfacing technologies have both a number of advantages and certain disadvantages. The stick electrode surfacing is characterized by a significant number of defects requiring additional costs for their elimination. Manual argon-arc surfacing that provides the highest quality of deposited layers is characterized by relatively low productivity. For its implementation, highly qualified welders are required. Mechanized surfacing with a consumable electrode in a shielding gas environment is more productive, however, it is difficult to control the heat input and the ratio of the substrate and electrode material fractions. In addition, all of the above technologies are characterized by the melting of the base metal and significant thermal impact on it, which is a major fault. Notice that when implementing any techniques of manual or mechanized surfacing, it is impossible to obtain uniform thickness of the deposited layer. Submerged surfacing has limitations, since it provides surfacing of only simple, almost flat surfaces.

Improving productivity and the quality of work performed provides automation of the surfacing processes. Automatic surfacing with a non-consumable electrode with filler wire feed provides the process continuity with efficient regulation of the substrate metal fractions in the overlay. In this case, constant monitoring of the non-consumable electrode condition is required, since when its working surface is worn out, the melting ability of the arc decreases sharply. In turn, with more efficient automatic surfacing with a consumable electrode, even with the addition of a filler wire [6], it is more difficult to provide a minimum penetration of the base metal.

In recent years, coatings on pipe fittings are performed by laser and plasma surfacing with filler metal in the form of a powder or filler wire [7, 8], FLSP. Laser surfacing has a number of advantages, as it provides minimal thermal effect on the substrate. A significant disadvantage of laser surfacing with an additive in the form of a powder is its irrational use, since it partially does not fall under the laser beam and remains unused. In case of using filler wire, there are problems with its melting due to the requirements for accuracy of guidance under the beam. Unfortunately, plasma-powder surfacing has similar problems with the use of powder materials. Replacing the powder with a filler wire creates problems for its absorption by the surfacing puddle. Combined plasma-arc surfacing is characterized by the complexity of synchronous control of heterogeneous heat sources. As noted by a number of authors, under FLSP, increased porosity and characteristic chips of the sprayed metal are often observed.

Therefore, for the anticorrosive surfacing of pipeline valves, new technical solutions that use technologies and automation tools that have already been tested in practice are required. Now in the park of industrial robots in the industrialized countries, the majority are robots that reproduce the movements of human hands during working operations. The application of such robots to displace the welding torch could not only lower the qualification requirements, but also reduce their subjective influence on the quality of operation [9].

Research Results. Given the automation capabilities, a high-tech process of robotic anticorrosive surfacing using a consumable electrode with an additional filler metal feed to the front welding puddle for shielding the thermal effect of the arc (Fig. 2) could be such an advanced way.

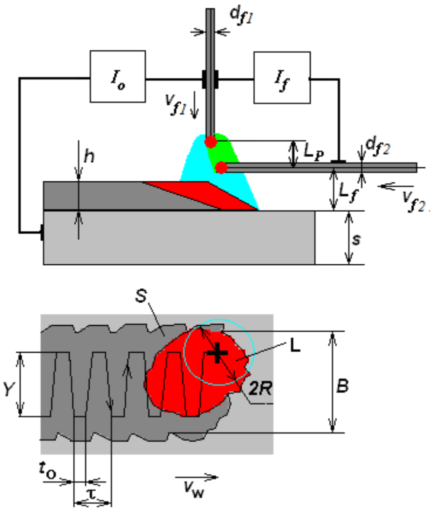


Fig. 2. Diagram of surfacing using a consumable electrode with filler wire feed and transverse oscillations of the burner: I_o, I_f are currents of the main and additional arcs; R is the radius of the arc torch; s is the thickness of the substrate; d_f, v_f are the diameter and wire feed speed; Y, t_o, τ are parameters of transverse vibrations; *L,S* are melt and overlay

According to the authors, this surfacing technique has sufficiently broad processing capabilities for regulating heat input and penetration in a wider range, since it provides the use of operating time for controlled droplet transfer of electrode metal [10] and the creation of optimal conditions for melting the filler wire [11]. In addition, the possibility of delivery of nanostructured additives, studied now a lot, through the filler wire will improve the microstructure and properties of the weld deposit. It is clear, the best assimilation of the filler wire by the surfacing puddle will provide its concurrent heating. As noted in [12], for the formation of wider layers in a smaller number of passes at a low integrated surfacing speed, it is preferred to use transverse oscillations of the burner. Such vibrations will reduce the likelihood of the formation of quenching structures that initiate manifestations of corrosion. However, only high-tech technology-intensive enterprises that seek to strengthen their advantages in a competitive environment can make full use of such developments [13]. Unfortunately, the industrial application of the proposed anticorrosive surfacing of sealing surfaces of pipeline valves is hindered by a host of unsolved problems (Fig. 3).

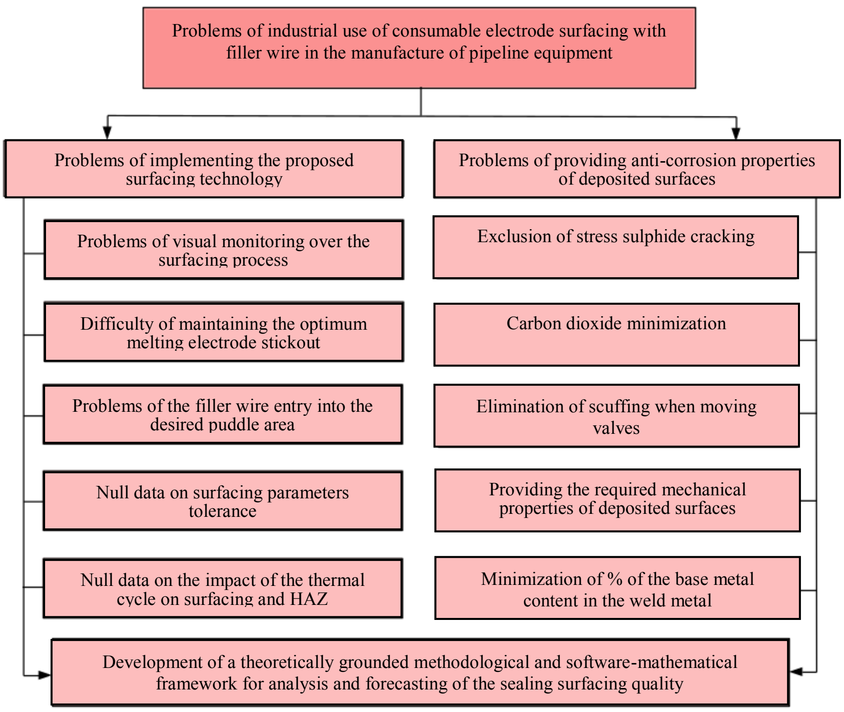


Fig. 3. Problems of industrial application of consumable electrode surfacing with an additional filler wire

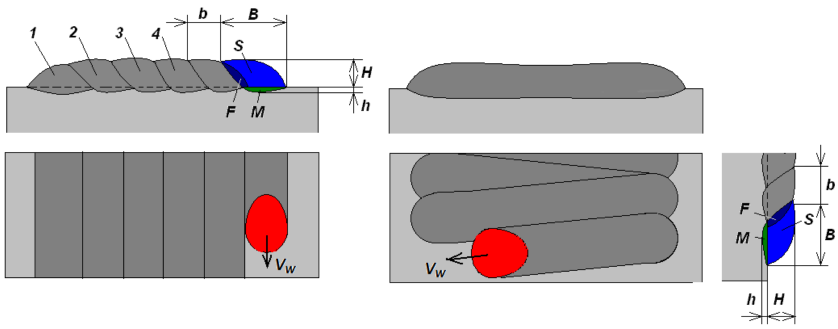
To solve the above problems and implement successfully the proposed anti-corrosion deposition process, it is necessary to develop a theoretically grounded methodological and software-mathematical framework for analysing and predicting the quality of deposited surfaces. The solution to the optimization problem of the proposed surfacing technology is complicated by a large number of parameters: speed of surfacing and wire feed, its diameter, voltage and arc current, amplitude, period and shape of vibrations, initial temperature of the substrate. Quality indicators are also important: size and shape of the deposited layer, penetration depth and thickness of the surfacing, chemical composition of the deposited metal, properties of the deposited layer. It should also be taken into account that the optimization of surfacing technology requires a large number of experiments, in most cases, very complex and expensive.

Currently, among modern research techniques of welding and surfacing processes that reduce the time and number of experiments, physical and mathematical simulation is distinguished. The efficiency of surfacing processes based on computer modeling is shown in a number of papers [14, 15]. Thus, in the paper [14], the hardening surfacing through physical and mathematical simulation was analysed. Modeling determined the optimum penetration depth and width of the surfacing puddle at which mixing of the deposited metal is minimized. Unfortunately, this work did not consider the conditions for guaranteed maintenance of a base metal content of less than 2–5% in the final layer.

The tasks of the surfacing technology development by computer engineering analysis methods were formalized in [15], which considered the technology of plasma deposition of copper rings on steel tube blanks with transverse plasma torch vibrations. However, this work results are not applicable for anticorrosive surfacing of coatings, and the process itself differs significantly from the consumable electrode surfacing.

When surfacing steels containing refractory metals on low- and medium-alloy steels, it is difficult to avoid the formation of quenching structures and cracking. Statistical models described in [16, 17] provide estimation of the probability of the formation of quenching structures. Approaches and results of these studies can be partially used to assess properties of the deposited metal and substrate.

Discussion and Conclusions. The above examples show that existing advances in computer simulation of welding and surfacing processes cannot solve the problems of industrial implementation of the proposed technology for corrosion-resistant surfacing. Therefore, the primary task is to develop a mathematical model of the anticorrosive consumable electrode surfacing with an additional filler wire and transverse vibrations of the welding burner.The model should provide virtual reproduction of melting electrodes of the specified diameters at given feed speeds, the formation of a puddle under the heat and force impact of the arc and the flow of electrode droplets, as well as the reproduction of the thermal cycle with the subsequent calculation of the ratio of the structural components of the deposited metal and the substrate metal. The system of equations of the model can be solved by numerical techniques, for which purpose a special computer program should be developed. Such a program should provide the reproduction of multilayer surfacing considering its typical dimensions of the deposited layers (Fig. 4), which requires modeling the sequence of their laying.



a) *b)*

Fig. 4. Typical dimensions when surfacing with bead welds (*a*) and with transverse vibrations (*b*): 1 ... 4 are roller numbers, V_w is burner travel direction; *B* is puddle width; *b* is arc pitch; *h* is penetration depth; *H* is deposition height; *S, F, M* are areas of surfacing, melting of the previous roller and melt of the substrate

The simulation validity, compliance with experimental data, is a challenge. An adequate model can assess the effect of parameters on the quality indicators of the formation of weld beads, primarily, on the chemical composition, geometry and mechanical properties of each weld bead.

Fig. 5 shows the sequential algorithm for solving problems on determining parameters of the anticorrosive consumable electrode surfacing with an additional filler wire.

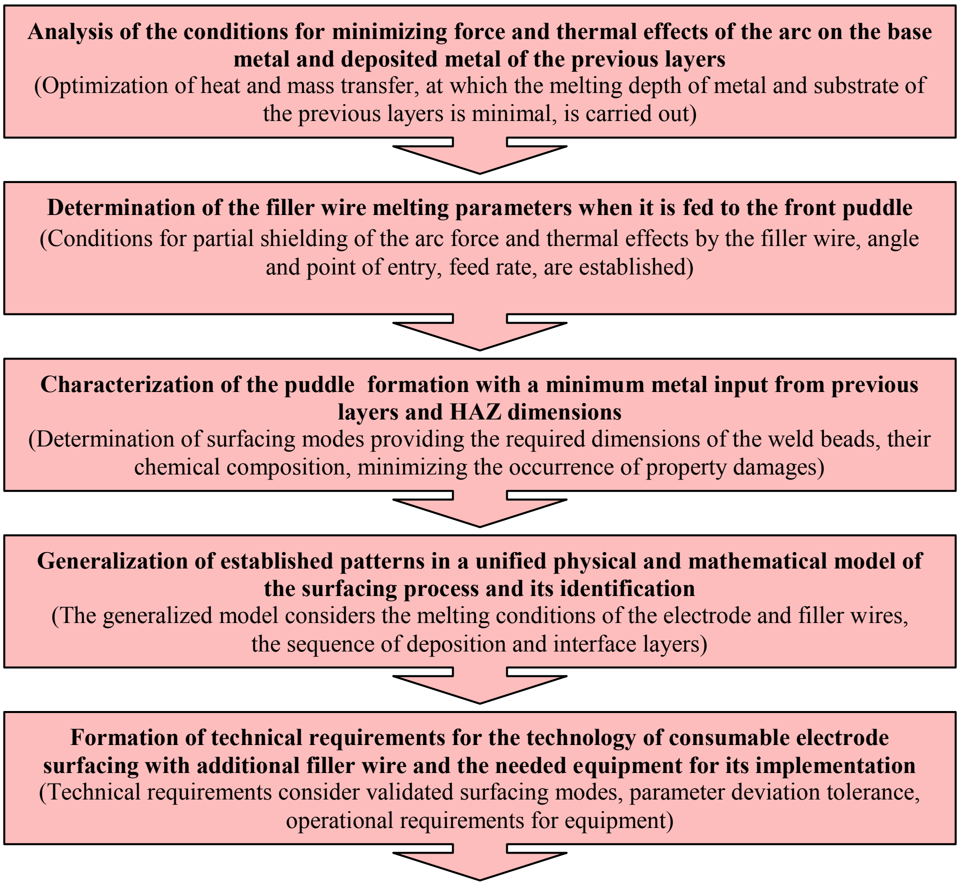


Fig. 5. Sequential algorithm for solving problems on optimizing the process of consumable electrode surfacing

Practical implementation of the proposed algorithm will provide establishing a clear relationship between the anticorrosive surfacing process parameters and the quality indicators of the deposited layer formation, determining the program for their optimization to maintain the required operational properties of pipeline valves. In turn, the determination of optimal surfacing parameters will help to form more reasonable demands for the proposed surfacing technology and the selection of the necessary robotic equipment for its implementation.

Undoubtedly, in the near future, such a systematic approach will help to solve the identified problems in the development and implementation of the technology of pipe valve sealing surface consumable electrode welding with an additional filler wire, which will guarantee the needed operational properties of such an important regulatory element of oil and gas equipment.

Conclusions

1. An advanced way to provide the required operational properties of pipeline valves with a significant increase in the surfacing productivity and quality during its manufacture is the introduction of anticorrosive surfacing technologies using a consumable electrode with the supply of an additional filler wire.

2. For the industrial application of the proposed deposition technology, it is required to conduct a series of studies aimed at assessing the impact of process parameters on the quality of formation of the deposited layers and maintaining the needed operational characteristics of pipeline valves.

3. Existing methods for modeling surfacing processes cannot solve the problems of industrial introduction of a consumable electrode facing technology with an additional filler wire. This condition necessitates the development of an original mathematical model of the surfacing process providing its virtual reproduction under the puddle formation, as well as the thermal deposition cycle with the calculation of the ratio of the structural components of the deposited metal and the substrate metal, the chemical composition of the deposited layers.

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