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THE EXAMPLES OF DIGITALIZATION OF FOUNDRY: VIRTUAL ENGINEERING, DIGITAL TWIN AND ADDITIVE TECHNOLOGIES

The concept of "virtual engineering" as a modern interpretation of methods of design, balancing and commissioning of the process, in particular, the process of metal casting in the foundry is examined. Virtual engineering is necessary to update information from any engineering objects in computer-aided design systems. The article considers the main methods of additive production of models using sand moulds for the manufacture of metal castings, where the product is increased layer by layer by the method of 3D-printing, and the process is controlled by a computer program. The data on the volume of growth of the market of additive technologies and an example of a printer for wire melt printing are given.

***Keywords**: digitalization, engineering, additive production, metal casting, digital twin, foundry technology, mould, 3D-printing.*

Introduction

The age of information technology dictates to the world its priorities. These priorities should be taken into account because it is a prerequisite for building a competitive national economy. Transition to "digitalization" is the most important priority in the XXI century [1]. It is actually a digital transformation of most processes and in general a change in the approach of business, business processes and relationships between people.

Large-scale spread of digital technologies can provide economic growth, create a synergistic effect. Thus it can ensure a positive result of the system under study, relative to the results of its components, which extends to economic, social, technological, intellectual and infrastructural components of development. Digitalization is one of the "trademarks" of the new economy. This new economy is formed within the post-industrial period of economic development. This is done through the introduction of scientific and technological progress and innovative management methods, intellectualization of human capital, the use of advanced technologies, accelerated development of knowledge-intensive industries of economy, giving priority to the production of knowledge and services based on widespread use of information technology [1]. Digitalization is designed to radically change production. Three methods of digitalization are presented in this paper on the examples of the manufacture of cast metal structures. Creation of high-tech products and productions is an inter-

dependent complex of scientific, research and development, technological and production works.

The aim of this work is to demonstrate the application of the method of digital twin of products, which is determined by what indicators should be optimized for the characteristics of the product or its production technologies. In order to do this, designers use the method of computer simulation in the form of digital data. This method, along with empirical and theoretical methods, is considered as the third way, despite the fact that the models can not provide universal knowledge.

Virtual Engineering

Consider the concept of the term virtual engineering as a modern interpretation of the design, balancing and commissioning of the process, including the process of metal casting. The creation of high-tech products and industries is an interdependent set of scientific, research and development, technological and production work, known in the literature as "engineering". Engineering is the preparation of feasibility studies and projects; design of new technology; technical assistance in carrying out specialized work; construction, investor and technical control; consulting services; conducting tests and inspections of equipment and machinery; also, often, processing of raw materials of the customer with use of original technology [2].

Engineering is an infrastructure of innovation processes. In recent years the term "virtual engineering" is used increasingly. There is even the subject "Foundry Technology Engineering" (FTE) in some technical universities. Virtual FTE [3] refers to the use of computer tools for the development of technologies for the manufacture of metal castings, design of shops and foundry equipment using modelling programs and engineering calculations for comprehensive assessment, optimization, cost analysis and planning. It gives a possibility to integrate knowledge-based tools into technological processes and production facilities.

According to the National Chamber of Engineers [4], engineering consists of such design work as preparation of terms of reference, pre-investment research, development of design documentation, development of working documentation. It also includes the functions of the designer for project implementation: collection of initial data and inspection of production conditions, following-on, and selection of equipment, preparation of technological regulations, and participation in balancing and commissioning, preparation of documentation "as built", setting into operation and training of customer personnel.

In particular, the virtual FTE of the consumable pattern metal casting process, performed in Physic-technological Institute of Metals and Alloys of the National Academy of Science of Ukraine by specialists of the Department of Physics and Chemistry of Casting Processes [5], in addition to the design of production equipment, also includes design of modelling equipment, treatment equipment, process automation and environmental monitoring of the entire production cycle, which at the stage of balancing and commissioning are activated during the introduction of new casting processes in the creation of productions.

Digital Twin

Modern development of digital technologies has allowed increasing computing power and reducing the cost of their use. It gave a possibility to combine information technology with operational processes to create digital twins (DT) of the technological processes. The DT of the consumable pattern metal casting process (CPMC) is considered as a digital copy to optimize its efficiency. DTs contribute to the rapid development of modern companies. They simplify the maintenance of technical systems; increase the efficiency of risk management of errors and failures, which increases the stability of work. The DT allows providing the key parameters of production products according to the input data of the equipment. A DT is a virtual reproduction of the working state of a real physical object, process, system, or an entire service. It can be a virtual duplicate of a part, product, equipment, technological process, production sites, shops or even factories. In essence, it is a set of mathematical models that describe the state of the object and all its elements. In the general case, the DT

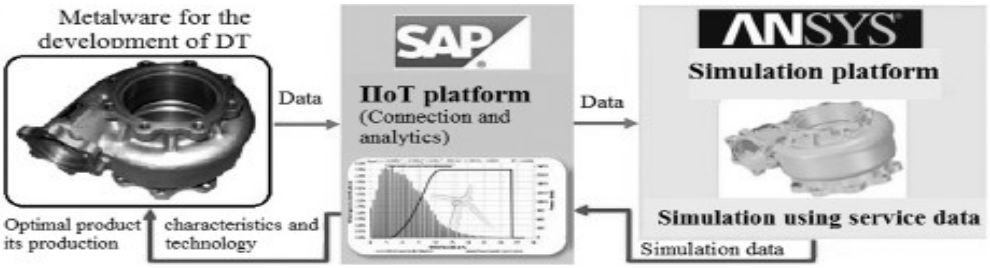

Fig. 1. The scheme of creation of the DT of a cast metalware, based on work [6]

includes: a geometric model of the object; a set of design data of parts, assemblies or object as a whole (mathematical models that describe all the physical processes occurring in the object); information on technological processes of manufacturing and assembly of separate elements; some data on testing of the object, (for example, indicators of sensors on which the design data can be confirmed).

Thus, the DT gives a possibility to simulate in cyberspace the change in the state and characteristics of the entire product when changing the characteristics of any of its elements or technological operations of its production.

Let's consider in more detail the concept of the term DT in relation to the exact cast metal structure. Today, the topic of the DT is on the agenda of many global companies. The content of the DT products (castings) is determined primarily by what indicators of the characteristics of the product or technology of its production should be investigated and optimized. At the same time, designers and technologists get a possibility to transfer the product's operational data to a computer simulation model to verify their calculation models and refine various parameters [6]. Developers in the process of operation of products receive additional data about their work in real operation. It allows the manufacturers to improve the product, increase its reliability and quality.

The data are received and sent to the software environment-platform from the product (metalware) using sensors and detectors (possible virtual sensors and detectors, where the installation of physical sensors and sensors is not possible). This platform processes, analyzes and, if the sufficient tools of analytical or statistical methods are available, makes predictive conclusions about the future state of products, suggests improving the methods of its production or design [6]. In particular, the Industrial Internet of Things (IIoT) platform is such a platform.

If the IIoT platform cannot provide such information for complex technical products, then multiphysical simulation comes into play. It is able not only capture the "behaviour" of the real product, but also perform operations such as finding the causes of problems, implementing scenarios "what if », installation of additional virtual sensors and detectors in order to obtain additional data, and much more (Fig. 1). Then the DT is considered as a virtual response of a real physical product in the form of an integrated multi-domain simulation system, which reflects the conditions of its operation and production [6].

The Main Methods of Additive Production

Let's consider the main methods of additive production of models and sand molds for the manufacture of metal castings.

Additive production (AP) allows the method of 3D printing to increase the product in layers by a controlling computer program [6, 7]. The main advantages of AP are:

- reduction of material costs (up to 75%);
- the possibility of manufacturing products of complex geometry;
- does not require additional processing;
- the time of technological preparation of production reduces drastically and requires a minimum technological equipment.

The introduction of 3D-printing from metal in Ukraine is slowed down by the lack of own produc-

tion on 3D-printers that manufacture the metal, sand moulding mixtures or model material products; as well as by the lack of spent compositions of moulding mixtures and metallic material. About 70% (by tonnage) of foundry goods (with two dozen brands of foundry goods) and 10% of steel (up to hundreds of brands of cast steel) in the world are casted by traditional methods now. It is possible to produce the casts of the same standardized in Ukraine brands of foundry goods and steel by AP technology of the models and sand moulds today, especially of high-strength foundry goods (which reaches 35% of world volume of casting). Metal printing is considered in [7, 8]. The main schemes of AP foundry models and disposable sand moulds according to the data of the LLC "3D Techno" (Ukraine) are shown in Fig. 2.

The global AP market is growing rapidly. According to the leading industry analytical company SmarTech Publishing, which specializes in the markets of AP, the total volume of the global market for additive production in 2019 amounted to 11,2 billion US dollars. This market is growing by 18–20% per year (see Fig. 3).

Creating 3D printing technology with metal, designers seek to reduce the cost of the process, expanding its availability. As a raw material for such printers they often use metal powder, of which the layers of printed product are built up with the help of a powerful laser or other high-energy beam.

The 3D printer developed by Master of Samara University S. Repin is recently patented [10, 11].

This printer uses the technology of melting metal by induction heating, like induction furnaces, which are widely used in foundries. The printer was tested by printing by melting aluminium wire and its alloys. Printing accuracy — 0,2–0,5 mm, and the weight of the device is up to 300 kg, which is many times less than of the existing similar printers on the market, which weigh from one to three tons. For mobility, the design of the printer is made modular, and the technology is compatible with most machines with numerical program control. By melting the wire, printing costs are reduced by almost an order of magnitude compared to powder metal printing. This example demonstrates the high potential of application of long-mastered by foundries melting and foundry methods for their implementation in 3D printing.

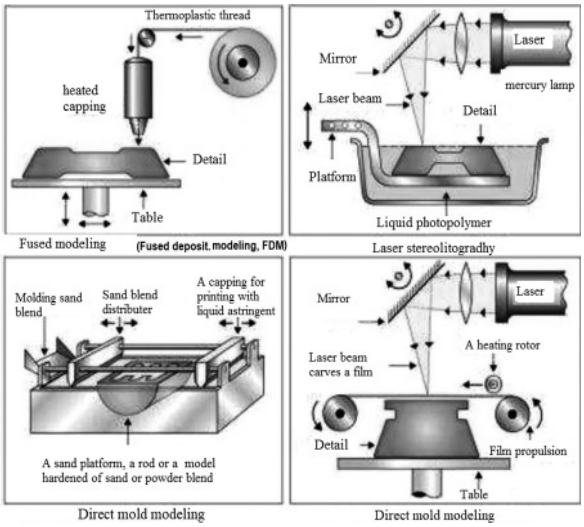

Fig. 2. Basic schemes of AP of foundry models and sand molds

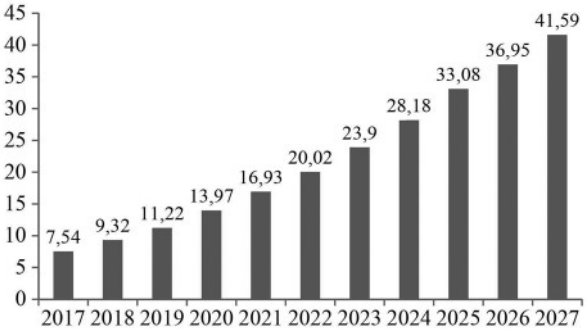

Fig. 3. The total market volume of additive technologies in 2017–2027 [9]

Conclusion

Summing up this review, the relentless trend of digitalization of material production should be noted. The accumulation of large data sets and the rapid development of processing technology, including use of cloud computing, automation of production and complexity of engineering, electronics and other industries contribute to it. This is the result of the synergy of the development of artificial intelligence, the Internet of Things and other new

solutions. Digital tools allow not only to test hypotheses about the ways how to build technological schemes of equipment, but also to conduct a virtual launch and setting up of complexes before they are created in metal.

This significantly reduces the time of introduction into production and reduces the cost of correcting errors in the design, including new foundry processes or castings of optimal structures, in particular when using additive technology for their production.

The article considers the main methods of additive production of models and sand molds for the manufacture of metal castings, where the product is increased layer by layer by the method of 3D-printing, and the process is controlled by a computer program. The data on the volume of growth of the market of additive technologies and an example of a printer for wire melt printing are shown. The concept of "virtual engineering" as a modern interpretation of the design, balancing and commissioning of the process, including metal casting, is considered.

Virtual engineering of the consumable pattern metal casting process and in addition to the design of production equipment includes the design of model equipment, purification equipment, as well as the means of automation of technological processes and environmental monitoring of the entire production cycle, which are in the process of balancing and commissioning in the conditions of newly created productions.

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ПРИКЛАДИ ДІДЖИТАЛІЗАЦІЇ ЛИВАРНОГО ВИРОБНИЦТВА: ВІРТУАЛЬНИЙ ІНЖИНІРИНГ, ЦИФРОВИЙ ДВІЙНИК, АДИТИВНІ ТЕХНОЛОГІЇ

Вступ. Епоха інформаційних технологій диктує світу свої пріоритети, врахування яких є обов'язковою умовою побудови конкурентоспроможної національної економіки. Найважливішим пріоритетом у XXI ст. є перехід до «цифровізації» (*digitalization*). Масштабне поширення цифрових технологій здатне забезпечити економічне зростання, створити синергетичний ефект, що поширюється на економічні, соціальні, технологічні, інтелектуальні й інфраструктурні складові розвитку. В статті на прикладах виготовлення литих металоконструкцій представлено три методи цифровізації, покликаних в корені змінити виробництво. Створення високотехнологічних виробів і виробництв є взаємозалежним комплексом наукових, проектно-конструкторських, технологічних і виробничих робіт.

Метод цифрового двійника виробів визначається тим, які показники слід оптимізувати щодо характеристик самого виробу або технології його виробництва, при цьому конструктори застосовують симуляційні моделі у вигляді цифрових даних.

Результати. Розглянуто основні способи адитивного виробництва моделей та піщаних форм для виготовлення металевих виливків, за якими пошарово нарощується методом 3D-друку виріб, а процес управляється програмою комп'ютера. Приведено дані про об'єм росту ринку адитивних технологій і приклад принтера друкування розплавом з дроту.

Висновки. Розглянуто поняття «віртуального інжинірингу» як сучасного трактування проектування і пусконалагодження процесу, в тому числі лиття металу. Віртуальний інжиніринг процесу лиття металу за газифікованими моделями виконується у ФТІМС НАНУ у відділі під керівництвом О.І. Шинського і, крім проектування виробничого обладнання, включає проектування модельного оснащення, очисного устаткування, а також засобів автоматизації технологічних процесів і екологічного моніторингу всього циклу виробництва, що проходить пусконалагодження в умовах створених виробництв.

Ключові слова: *цифровізація, інжиніринг, адитивне виробництво, лиття металу, цифровий двійник, ливарні технології, виливок, 3D-друк.*