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Prospects and directions of digital transformation in foundry

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Abstract. The time of information technology determines its priorities, which are a prerequisite for building a competitive production and economy. The ubiquitous spread of digitalization is one of the basic principles of new economy, a new type of socio–economic structure that is gradually being formed in the modern world through the introduction of scientific and technological progress and innovative methods of management, intellectualization and capitalization of human knowledge, the use of advanced new information and material technologies, accelerated development of knowledge-intensive sectors of the economy, the formation of creative, efficient, rational information and material production. Currently, at large foundries with mass and large-scale production of castings, the task of automating the control of technological processes using digital control systems was solved in general. They implement algorithms for controlling technological processes of casting in closed circuits (locally). The systems under consideration allow to implement optimal control strategies and automatically perform sequences of operations (start and stop of equipment; calculation and input of metal charge; calculation of formulations, dosing and mixing of molding and core mixtures) of multi-stage periodic casting processes. Digital transformation can significantly change the established practice of foundry production (from direct control and management of technological processes to business planning and document management). The transformation will have an impact on all parameters of the enterprise: economic efficiency of production (productivity, operating costs); reliability (operational readiness); safety (number of incidents); compliance with legislative norms on ecology. The technological criterion for success of the digital transformation of foundry production will be the release of a nomenclature of castings with a minimum level of defect, commercial – the release of a nomenclature of castings in demand on the market (machine parts and mechanisms), with a minimum self-cost, which is determined by the technological level of preparation of the production and its implementation and, as a consequence, low costs and optimal quality of molds, metal and castings.

Keywords: foundry, technology, management, digitalization, transformation, quality, efficiency, control, system

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Перспективы и направления цифровой трансформации в литейном производстве

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Аннотация. Время информационных технологий определяет свои приоритеты, которые являются обязательным условием построения конкурентоспособного производства и экономики. Повсеместное распространение цифровизации – один из базовых признаков новой экономики, нового типа социально-экономического устройства, постепенно формируемого в современном мире путем внедрения достижений научно-технического прогресса и инновационных методов хозяйствования, интеллектуализации и капитализации человеческих знаний, использования передовых новейших информационных и материальных технологий, ускоренного развития наукоемких отраслей экономики, становления творческого, эффективного, рационального информационно-материального производства. В настоящее время на крупных литейных предприятиях с массовым и крупносерийным производством отливок в целом решена задача автоматизации управления технологическими процессами с использованием цифровых систем управления. Они реализуют алгоритмы управления технологическими процессами литья в замкнутых контурах (локально). Рассматриваемые системы позволяют реализовывать оптимальные стратегии управления и автоматически выполнять последовательности операций (пуск и остановку оборудования; расчет и ввод металлошихты; расчет рецептур, дозирование и смешивание формовочных и стержневых смесей) многостадийных периодических литейных процессов. Цифровая трансформация может существенно изменить сложившуюся практику работы литейного производства (от непосредственного контроля и управления технологическими процессами до бизнес-планирования и документооборота). Трансформация окажет влияние на все параметры предприятия: экономическую эффективность производства (производительность, эксплуатационные затраты); надежность (эксплуатационную готовность); безопасность (количество инцидентов); соответствие законодательным нормам по экологии. Технологическим критерием успешности цифровой трансформации литейного производства будет являться выпуск номенклатуры отливок с минимальным уровнем дефектности, коммерческим – выпуск номенклатуры отливок, пользующихся спросом на рынке (детали машин и механизмов), с минимальной себестоимостью, которая определяется технологическим уровнем подготовки производства и его реализацией и, как следствие, низкими затратами и оптимальным качеством форм, металла и отливок.

Ключевые слова: литейное производство, технология, управление, цифровизация, трансформация, качество, эффективность, контроль, система

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Introduction

Modern production and enterprises are characterized not only by their technological flexibility but also by their ability to adapt their business models and strategy to changing conditions.

Digital transformation refers to the integration of IT and digital technologies into all company processes, which involves not only the use of modern equipment but also the modernization of management approaches [1; 2]. Progress in digital transformation is achieved by abandoning conservative models of operation and transforming them into more dynamic and adaptable ones.

Digital transformation should be based on modern information technologies and equipment, starting with the modernization of the top management level. This includes the implementation of a ERP system for planning, material flows and finance, personnel, and communications, among others. Additionally, it requires the improvement of digital technological competences and mindset of employees, their adaptation and training to innovations, and the adoption modern management and work style. It is crucial to involve and incentivize employees during the conversion to modern stages of development [3 – 5].

Digital transformation encompasses all aspects of a company's activities, from the creation and storage of Big Data (such as results of analysis, images) to the use of industrial television, remote monitoring devices for equipment status, and mobile applications for production control. This modification of production technologies represents a shift in the approach to industrial processes, enabled by digitalization.

One of key functions of digital production is control and identification [6 – 8]. This approach allows for a more flexible production process, even down to the individual item. However, digital production entails not only the control and identification of products, but also the creation of electron libraries, logs, and product passports. Additionally, online digital control with subsequent mathematical processing and analysis of results; development of specialized platforms to control product operation (feedback), and forecasting and technical diagnostics of product quality are all critical components of digital production [9 – 11].

Based on the analysis of the opinion of Russian [12 – 14] and expatriate [15 – 18] experts, four priorities of digital transformation in the industry can be identified:

– elimination of human participation from routine and dangerous production processes;

– creation of digital twin aggregates;

– control and distribution of resources;

– arrangement of modern communication culture.

Digital twin aggregates involve optimization of energy consumption and resource planning in production, supply chains, maintenance and repair, as well as models of the various stages of production processes.

Challenges of digital transformation of foundry industry

Digital transformation for the foundry industry is still in its early stages, and currently only around 20 % of the potential benefits of digital technologies have been realized.

Large foundry enterprises have successfully implemented computerized process control systems to automate the control of production processes. These systems allow for closed-circuit control using predefined algorithms, the implementation of optimal control strategies, and the automatic execution of procedural sequences such as equipment startup and shutdown, calculation and feeding of metal charges, and dosing and mixing of molding and core mixes for multistage periodic foundry processes.

In contrast to the automation of production process, production management tasks are typically not automated. This list of tasks includes, but is not limited to the preparation and execution control of production plans, optimization and control of production methods, forecasting and diagnosing defect structures, monitoring the state of main equipment, ensuring personnel, regulating emissions, and ensuring equipment reliability [12 – 14]. Due to the diverse nature of these tasks, the inadequate implementation of systems capable of automating their execution, insufficient initial data for operating such systems, and incomplete integration of existing software, much of the production management is still performed manually and not in a closed circuit [15 – 18]. However, digital transformation has the potential to close this circuit and enable the execution of such tasks in automated manner. With complete and real-time data on production, company employees can utilize analytical applications, both general-purpose and specialized, to develop solutions and execute them. Additionally, the involvement of branch experts, who have access to the necessary information, can aid in this process. The control of solutions to be executed will be based on real-time data automatically received from computer control systems and other sources.

Another group of tasks, that can be significantly impacted by digital transformation is those involving dangerous production areas and remote sites. These tasks include field linemen walkthroughs, equipment status control, maintenance, equipment repair, and instrumentation control. New approaches enable access to information that was previously unavailable to employees working in hazardous areas and also reduce the number of visits required to such locations.

An essential aspect of digital transformation foundries is the significant shift in business processes that relate to the sales of finished products to consumers. As many large market players, including state corporations, multinational companies, and large amalgamations, have already embraced digital transformation in their primary activities for several years, in the near future, these entities will only purchase products, technologies, and services from producers, who can integrate into their digital platforms. Only in this scenario can suppliers be relevant for the strategic development of their customers.

The foundry industry is a production sector that utilizes various tools and techniques to provide mechanical engineering, instrumentation, and other fields of the national economy with cast workpieces and items.

In the near future, as part of digital transformation, each cast product will have a *Digital Passport* containing its entire lifecycle. The Digital Passport will include the following information in a general format [19; 20]:

– a unique item number that identifies the item's serial number and provides personal information about the specific item;

– item specifications, including an item passport;

– materials and/or components used in the item's fabrication;

– a list of equipment used for item fabrication, including all parameters of the production chain, such as direct operators (shifts, crews, workers depending on the production procedure), involved in the item fabrication;

– test results and diagnostics at each process stage of item's fabrication;

– data on methods and means of quality control of the item, including results obtained during operation;

– data on defects, reparatory and technological repairs along the entire chain of item fabrication;

– conditions of item storage and operation;

– terms of destruction, disposal or recycling of the item.

This approach will enable direct communication with customers, facilitate operational electronic document management of manufactured products, prevent counterfeit products, reveal possible reasons for the failure and breakdown of the item as part of the equipment, forecast its technical state, and improve the level of quality management. An *Online* working space will be created for online exchange with reliable documentation from the manufacturing plant and interaction between supplier and customers [21 – 23]. In addition, the manufacturer can acquire a significant amount of analytical data, which, if used properly, could keep the expenses for fabrication of the cast item low (competitive) [24].

Digital tools of foundry production

The digital transformation of the foundry industry is an imperative for its survival, and it requires the application of modern digital tools at all process stages of the casting process (Table).

Among the industries where digital foundry transformation will be implemented first are car manufacturing, aircraft industry, shipbuilding, motor production, mechanical engineering (including atomic industry, oil and gas, heavy, and specialized), railroad transport.

Foundry enterprises must initiate the development of a digital transformation strategy that takes into account the following important aspects:

– process digitization: solutions that simplify technological production processes, maintenance and repair of equipment, administrative processes, and mobile solutions for working personnel);

– robotization and automation: solutions that reduce or eliminate human participation in non-critical processes, as well as solutions that improve control and stability of production processes);

– step-by-step quality control of finished products: solutions that establish a system for the accounting and identification of finished products at production site and the development of a *Digital Product Passport*;

– system control of company assets: solutions aimed at establishing interaction in a unified information system of the manufacturer, suppliers, and consumers);

– advanced business intelligence and artificial intelligence: solution that enable decision-making related to the diagnostics and forecasting of technological, production, and business processes, and the development of intelligent systems for dynamic process control).

Conclusions

The technological criterion for a successful digital foundry transformation will be the manufacture of cast products with a minimal level of defects. The commercial criterion is the production of cast products that are in high market demand, such as parts of machinery and mechanisms, with minimal prime cost. The prime cost is determined by the technological level of production preparation and its implementation resulting in lower expenses and optimum quality of molds, metal, and casting. This requires a shift from revisional to continuous optimization of business processes.

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Digital foundry tools

Цифровые инструменты литейного производства

Technological and organizational operations	Digital tools
Preparation of production, technology of foundry mold and mold patterns [25 – 27]	– creation of computer 3D model of casting using 3D solid state surface parametric design systems; – design of gate system, simulation, and optimization of casting using LVMFlow, ProCAST systems; – CAD, virtual tests, digital twin aggregates (DTA); – preparation of a drawing set of foundry technology based on CAD systems; – application of additive technologies (AT); – technological design based on CAD systems; – application of CNC machines.
Formation and fabrication of cores [28 – 30]	– robotic process automation (RPA); – AML and core making machines.
Blending, metal melting and die casting [31; 32]	– robotic process automation (RPA); – data analysis in supply chains; – smart warehouse (SW).
Finishing procedures of casting items (cooling, knockout, cropping and cleaning, elimination of casting defects, thermal treatment) [33; 34]	– robotic process automation (RPA); – computer vision (CV); – remote digital control (RCU).
Maintenance and repair [35]	– augmented reality (AR); – virtual assistant (VH).
Warehousing, storage, procurement and sales, disposal, and recycling [36]	– smart warehouse (SW); – product lifecycle management (*Smart Design*).
Quality control [37 – 40] and optimization of production [41 – 43]	– digital post-process control of production; – digital product passport (DPP); – *block chain* technologies; – recommended and intelligent decision support systems (DSS); – advanced business intelligence (BI); – artificial intelligence and machine learning (AI&ML); – digital business services and application for control and monitoring of production and other processes.

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