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Foundry production digitalization

V M Gruzman

Ural Federal University named after the First President of Russia B N Yeltsin, Nizhniy Tagil Technological Institute, 59, Krasnogvardeyskaya str., Nizhniy Tagil, 622000, Russia

E-mail: gruzman-vm@ntiustu.ru

Abstract. Domestic companies upgrade their production facilities as it is an imperative of the economy changing over to a new technological mode right now. Industrial companies use more automation and robotization of production, and the level of digital intellectualization is growing. Introduced into technological processes, digital technologies save time and costs of production and reduce the human factor effect. Foundry industry is no exception. The authors suggest considering a foundry process as a set of stages: designing and manufacturing casting models, preparation of charge materials, preparation of initial molding materials, smelting, mixing, casting metal in ladles, mold manufacturing, pouring smelt in mold, knocking castings out of mold, stumping and cleaning of castings, heat treatment of castings, quality inspection of castings. The article organizes information about the digital technologies used at each of the selected stages of the foundry castings by pouring the melt into sand molds. The application of computer technology, digital devices, and software is considered in detail at the stages of the casting model design, charging and molding materials preparation, sand mold manufacturing and casting quality inspection. Digital technologies optimize production, save time and costs.

1. Introduction

Domestic companies upgrade their production facilities as it is an imperative of the economy changing over to a new technological mode right now [1].

Industrial companies use more automation and robotization of production are being activated, and the level of digital intellectualization is growing. Introduced into technological processes, digital technologies save time and costs of production and reduce the human factor effect. Foundry industry is no exception.

A foundry is a complex of technological processes that involve many workers of various professions with their skill having a direct effect on the final casting product quality.

Most shaped castings in this country are produced by pouring the smelt into sand-clay molds. The process flow can be split into the following stages:

1. Designing and manufacturing of a casting model.
2. Preparing charging materials.
3. Preparing initial molding materials.
4. Smelting.
5. Mix preparation.
6. Tapping to ladles.
7. Manufacturing of molds.
8. Pouring the smelt into molds.

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9. Knocking-out of the mold.
10. Fettling and cleaning of castings.
11. Heat treatment of castings.
12. Quality inspection of castings.

Digital technologies introduced in the production processes are designed to create the potential for increasing the profitability of production, including foundry.

The results of the analysis and systematization of the experience of the authors, various sources on the use of digital technologies at each of the selected stages of the serial castings production process are presented below.

2. Materials and method

2.1. Description of the process of designing and manufacturing castings using computer technology

The entire cycle of design and manufacturing of castings in mass production using modern computer technologies consists of the following stages:

1. Obtaining a technical design specification for model pattern equipment, which includes a ‘flat’ design drawing with a foundry technology shown on it. Designing a 3D (three-dimensional) model of a cast billet, rods (if any), and Gating system in a CAD system.
2. Verification of the technology in the CAE system for foundry processes simulation.
3. Designing 3D models of the top, bottom, and core boxes.
4. Converting a 3D model into a set of hard copy design documents for model tooling.
5. Development of a control program for processing model tooling blanks on a numerical control (CNC) machine based on a previously developed 3D model using CAM systems.
6. Milling on a CNC machine, finishing the model tooling manually.
7. Verification of drawing parameters of the final setup equipment, including the use of digital control and measurement systems (CAI-systems), and filling in a certificate for the model kit.

In Russia, advanced steel making producers use CAD/CAE/CAM and CAI-systems for manufacturing model setup, as indicated above [2, 3].

Let us briefly consider the purpose of such systems.

Computer Aided Design (CAD) –‘designing using computer programs’. These are computer-aided design systems that provide geometric modeling and visualization of products or their parts in two and three dimensions. Up-to-date CAD systems include the following modules: modeling of a three-dimensional structure; building and execution of drawings; keeping textual design documents; filling in process charts.

CAD computer systems that can be used in the development of castings and setup design as as follows: COMPASS-3D, SolidWorks, Inventor, AutoCAD, T-FLEX CAD, NX etc.

Computer Aided Engineering (*CAE*) – ‘engineering calculations using computer programs’. CAE tools are useful for a wide variety of calculations of stresses, deformations, heat transfer, magnetic field distribution, fluid flow, and other parameters of continuous media. No need to explain how difficult it is sometimes to choose the best technology out of a variety of options. Sometimes the refinement of the design and technology takes a long time. So, a computer modeling systems have to be used to simplify the choice and reduce the time needed to work out the new part manufacturing technology. Foundry workers can use the CAE system as a tool for computing experiments in simulation of casting crystallization processes and formation of its structure and properties. Computational experiments in the design and pre-production make it possible to optimize technological processes and build performance data of cast parts in a targeted way.

CAE systems that are used for computer simulation of foundry processes: LVMFlow, Magmasoft, Poligon, ProCAST, SolidCAST, Procast, CastCAE, PowerCast, WINCast, CalcoSoft etc.

Computer Aided Modeling (*CAM*) – ‘pre-production using computer systems’. In the first place, CAM systems are intended for designing product processing on CNC machines and issuing control programs for various machines. Numerical control includes use of programmed commands to control a machine that can grind, cut, mill, stamp, bend, and otherwise turn workpieces into final parts. There are no fully automatic process preparation systems at the moment, but there are many good software packages that generate some code for CNC machines.

To prepare control programs for CNC machines, the following CAM systems are used: PowerMill, FeatureCAM, Mastercam, ESPRIT, Edgecam, Artcam, NX, SprutCAM, SolidCAM, Alphacam etc.

Computer Aided Inspection (*CAI*) – ‘survey using computer programs’. CAI systems together with contact and non-contact measuring devices make it possible to control the quality of physical models and products using a previously developed digital model as a reference.

The following systems are used to control the set-up manufactured: Power INSPECT, PC-DMIS, CAM2 Measure etc.

2.2. Digital technologies for charge materials development

At this stage of foundry production, information technologies are used for:

- chemical analysis control of charge materials;
- Automated control of materials in warehouses of the facility (foundry).

To perform real-time control of the charge chemistry, portable laser analyzers are used with carbon detection (LIBS technology), portable x-ray-fluorescence analyzers (XRF technology) are used as well, which allow you to quickly and instantly find out the chemical composition of the charge materials on the spot.

Automated material accounting makes it possible to track current inventory for planning purchases and handle workshop needs, increase the speed and accuracy of order handling and reduce the influence of the human factor on warehouse management.

As a rule, WMS systems are used to reach the above objectives.

WMS is a warehouse management system, in other words, it is software that makes it possible to automate warehouse operations.

To account for the movement of materials in the warehouse, ready-made WMS systems distributed in the its product market can be used (1C: WMS logistics. Warehouse management, YARUS WMS, WMS Logistics Vision Suite, LM7, Solvo WMS etc.) and systems developed for the needs of a specific company. In this case, software can be developed both by in-house IT-people and by a third-party developer.

2.3. Digital technologies for initial molding material development

Up-to-date computer technology and its elements can be effectively used at this stage of foundry production. E.g. a device was created for real-time control of the clay content in incoming batches of molding sand at one of the foundries, to control the process of preparing molding mixtures [4].

The device uses a ATMEL Atmega8 microcontroller. A two-line liquid crystal indicator is used to display the readings. A powerful led is used as a light source. Several photocells are located under the slide table.

The non-volatile memory of the microcontroller contains analytical dependencies for calculating the content of the clay component in the sand. During the measurement cycle, the microcontroller reads information from 9 sensors located under the tray and calculates the value of the clay component according to a specific algorithm using the selected coefficient for the brand of sand used at that company. The processing time for a sand sample is less than one minute, which gives a random variable ‘clay content’ large enough for a batch of sand being its general entirety. This makes it possible to determine the true clay content in an incoming sand batch. Reliable information about the fine component content in each incoming sand batch saves the binder, which is quite expensive, over its consumption time.

2.4. Digital technologies for smelting

At this stage of foundry process, computer systems can be used to control the smelting process. Such systems are normally developed for the needs of a specific producer and have their own architecture

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[5], consisting of modern electronic equipment (computers, computer networks, programmable logic controllers) and appropriate software that performs the necessary data processing and implements the user interface.

Developed intelligent computer systems make it possible to control smelting processes using neural network technologies [6].

2.5. Digital technologies for mixing

Many producers in this country use automated systems for preparing sand-clay molding mixes. Such systems normally consist of process equipment, automation tools (sensors) and a personal computer [7]. The latter serves as a system control center, which receives and processes information about the process progress and the controlled parameters of the molding mix.

2.6. Digital technologies for tapping to ladles

At this stage of foundry process, digital technologies, in particular the capabilities of computer equipment and software, are used to control the temperature of the metal [8].

2.7. Digital technologies for sand molds manufacture

Making sand forms, especially complex geometries, takes a lot of doing. Development of additive technologies has made it possible to apply alternately a layer of casting sand mixed with a hardener and a layer of binder. In fact, we are talking about the use of 3D printing technology for sand molds [9]. Modern technological complexes make it possible to design and manufacture molds of any complication and configuration, which saves a lot of material costs and time for preparing mass production.

First, as in the case of manufacturing any other product using a 3D printer, a 3D model of the sand mold is created (prepared).

Then, using this model, the 3D printer creates a sand injection mold, building the product layer-by-layer. Each mold layer consists of two materials added sequentially:

1. Molding sand: the sand feeding and leveling device feeds the molding sand to the surface to the construction chamber.
2. Binder: the print head selectively applies casting resins to the sand. The activator in the sand makes the binder strong. Thus, a single layer is formed. The process is repeated until the mold is built.

2.8. Digital technologies for pouring smelt into molds

In many cases, there is a maximum allowable speed limit for smelt rising up the wall of the mold cavity in the production of castings, for technological reasons. In these cases, software can be used to control the rate at which the melt enters the mold as a function of the time or of the amount of smelt from the casting start.

2.9. Digital technologies for knocking out from mold

For this and the next two stages of the foundry process, the use of digital technologies is not yet common.

However, computer technologies of knocking out from mold (in particular software) can be used to provide mathematical modeling to determine different characteristics of the rate of knocking out of the mold depending on various parameters. For example, modeling can be done to determine the temperature of the casting knockout. As is known, the higher the knocking temperature is, the shorter is the technological cycle of casting and the higher is the productivity of the molding and casting area. However, high knocking temperature is undesirable because of the casting destruction risk and defects formation or deterioration.

2.10. Digital technologies for cutting, cleaning and heat treatment of castings
At these stages, robotic tools can be used for cutting and cleaning of castings. As well as computer software for archiving and processing data (for example, data about the cupola operating mode).

2.11. Digital technologies for quality inspection of castings
Up-to-date digital technologies, including computer technologies, save time and money at the stage of quality inspection of castings. This is due to the fact that products are inspected using non-destructive test methods.

Such methods can identify most of the casting defects, including:

– cracks, shells, pores, inclusions;
– control the product geometry;
– control the casting surface and detect external defects.

So, at this stage, the following digital technologies are used.

1. Computer tomography. It can inspect products by obtaining a 3D model showing pores, voids and cracks in the casting.
2. Geometry inspection. The 3D models obtained using the tomography make comparison with the original data of computer-aided design systems (models built at the very first stage of the casting manufacturing process) possible.
3. Casting surface inspection using a digital microscope. Magnification from several tens to several hundred times is sufficient to visualize defects that are invisible to the naked eye.

These methods of casting quality inspection can quickly evaluate the product and require fewer man-hours compared to conventional destructive test methods.

At any stage of foundry process that accumulates input and output data, it is possible to mathematically simulate processes. This allows you to predict their progress and make real-time production decisions. Production floor practice uses more and more various computer simulation programs. All these programs are based on mathematical models. Models are very different: performed with a relatively complex mathematical apparatus and relatively simple. But they all contain three structural elements: variables, the relationship between variables, and a model parameter. For a particular company, input and output variables and the relationship between variables used in models of other enterprises may be quite adequate, but the model parameter must be different – its own. The most proper parameter has models built on the basis of technical and economic variables accumulated in the information dump of a specific company [10]. Of course, such a model will be a more reliable production control means due to a sufficiently large amount of information dumps in serial and mass production. In addition, a large amount of information makes it possible to build a preliminary draft version of the model without a complex mathematical apparatus by metallurgy engineers. This will significantly increase the probability of success when synthesizing a working version of the model with professional mathematicians.

3. Conclusion
Thus, it is easy to see that the use of digital technologies to a greater or lesser extent has an effect on all stages of the serial foundry process. At the same time, production is optimized by reducing the influence of the human factor on production processes and saving man-hours by automating operations. There is no doubt that digital technologies will continue to be coming into foundry production in the future.

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