High-tech small digital manufacturing in mechanical engineering

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Abstract. The article proposes creation of small high-tech engineering enterprises, which, in the context of a complete transition to digital technologies, will be able to solve effectively specific technological problems of large industrial enterprises and corporations. An example of an existing small digital enterprise is considered, where the technology for manufacturing foundry equipment for producing flat ingots for UC RUSAL is developed and implemented. Digital technologies are described using aggregation elements that were introduced during the modernization of the 6M610 longitudinally milling machine.

1. Introduction
The use of modern digital technologies in mechanical engineering is based on the use of 3D models at all stages from design to the manufacture of parts or assemblies with end-to-end network support [1-3]. At the same time, the production process is completely moving to a new high-performance and high-tech digital level of development and management, which requires the restructuring of the engineering industries themselves [3-4]. Digitalization at least an order of magnitude increases the production efficiency of the production itself, both by eliminating the influence of the subjective factor on the product quality and by reducing production costs, including due to a sharp change in the staffing. The traditional functions of a designer, technologist, operator of a CNC machine tool, instrumentation and automation engineer are combined and can be performed by one person who has undergone special training and has special training.

Thus, it becomes relevant to create small specialized digital enterprises in the engineering field that will effectively solve specific technological problems of large industrial enterprises and corporations, such as, for example, UC RUSAL, SUEK, ALROS, etc. Small digital enterprises can be independent, joint or subsidiary. The creation of large corporations of the latter will lead to a significant reduction in their costs of auxiliary production and, accordingly, total costs.

As an example, for UC RUSAL, we can propose the creation of small digital subsidiaries to solve the following technological problems:

- machining of foundry equipment (molds, pallets) to obtain various ingots;
- manufacturing of the foundry machine according to the developed documentation;
- repair and manufacture of electrolyzers (cathode bathtubs casings, anodes and anode holders);
specialized machining of various groups of parts (body parts and shafts of various sizes) to ensure the main production.

2. Organization of the machining foundry equipment production
An example of a specialized small digital enterprise in the Republic of Khakassia is Veles Engineering LLC, within the framework of which a digital technology for machining foundry equipment (molds and pallets) for RUSAL-ITC LLC has been developed and implemented [6-8]. Due to the digitalization of technological processes, the production personnel of the enterprise totals only 6 people. The introduction of digital technology allows for two-shift operation of the enterprise to produce from 50 to 70 molds and about 100 pallets per year. This capacity fully covers the needs of the Sayanogorsk, Khakass, Krasnoyarsk and Bratsk aluminum plants.

To introduce high-performance digital technology, the following equipment was independently upgraded by a small enterprise:

- 6M610 longitudinal milling machine with NC-110 CNC, designed for roughing three-axis and fine five-axis and six-axis machining of large molds and pallets;
- 65A80 vertical milling machine with NC-220 CNC, designed for rough three-axis machining of small (up to 1600 mm) and T-shaped molds and pallets;
- 16K20 lathe with NC-220 CNC, designed for machining of coffers and blanks for supports for pallets, as well as for the manufacture of small parts for molds;
- vertical boring machine 2C150MPF4 with CNC "NC-210", designed for the mechanical processing of fences, drilling holes in them for pallets, as well as for processing small parts for the mold.

The digital process itself provides for the following steps:

- preparation, assembly and analysis of 3D models in SOLIDWORKS environment;
- process development, processing modeling and preparation of control programs in the SprutCAM environment;
- preparation of necessary equipment and tools for the developed technological process;
- transfer through the network to the machine of control programs, information on the basis of the part and the necessary technological equipment;
- installation and binding of the part on the machine;
- milling parts on the machine.

The whole process can be performed by one specialist, who is responsible for the quality of work. The machines have the same operator interface, which makes it easier to work on them. Training a specialist allows him to work on any of the machines listed by technology. At the same time, one specialist can service several machines at the same time, since the installation and binding time of a part and a tool is much less than the time of automatic operation of the machine.

Direct costs for the development and implementation of digital technology for machining foundry equipment do not exceed 8 million rubles and were mainly spent on the purchase of the necessary equipment to upgrade the four machines listed above for specific digital technology.

3. Digital technology for machining foundry equipment
When upgrading the 6M610, 65A80, 2C150PMF4 and 16K20 machines, the following original technical solutions were proposed for the introduction of digital technology for machining foundry equipment.
For the 6M610 machine for automatic threading with a tap on the mold body in order to fasten the cover, a special unit was designed and manufactured for installing the encoder in the front head drive assembly (figure 1).

![Figure 1. Bevel gear with LIR-238A encoder.](image)

Preliminary roughing of molds and pallets is carried out in three-axis mode with maximum use of the technological capabilities of the machines (high rigidity and productivity of the machine itself) and the use of high-performance processing of aluminum alloys (figure 2).

![Figure 2. Roughing the outer contour of the pallet (a) and the pan bath (b).](image)

Finishing of molds and pallets is carried out using HSM technology, in the five-axis XYZCA version of processing with a high-speed motor spindle having liquid cooling (figure 3). Drilling of the main holes for water supply is carried out by the method of spatial increments (figure 4).
When drilling small diameter holes up to 0.8 mm along the W axis and knurling, instead of planing the inner surface of the mold, special devices are used that are attached to the mounting socket of the motor spindle (figure 5). This allows processing almost the entire mold or pan in two installations on the same machine.

At the first stage, in automatic mode, the main spindle performs three-axis roughing of the mold or pan. Then, using the same spindle with the use of machine taps for futurki at the pallet and for mounting the upper mold cover, threading is performed. At the second stage, high-speed finishing of molds and pallets in five-axis mode using HSM technology is performed. For this, a specially designed two-axis head is installed in the place of attachment of the frontal head, on which, depending on the technology, a high-speed motor spindle (figure 3), a linear module (W axis) with a small motor spindle (figure 5a) or a knurling device can be mounted (figure 5b).
If required, the inner surface of the mold is rolled. Figure 6 shows the process of rolling the inner surface of a T-shaped mold.

When processing the upper flange of the mold with a high-pressure oil supply system, you can use only one axis C of the spindle head and not use axis A, since all elements and holes are in the same plane. Figure 7 shows an example of using a spindle head with XYZCW axles when drilling nozzles with a diameter of 0.8 mm to supply oil under pressure.

**Figure 5.** Fastenings of the additional drive W with a small motor spindle (a) and rolling device (b).

Figure 8 shows the use of a spindle head with XYZC axes with horizontal mounting of the motor spindle when drilling holes for supplying oil to the ingot crystallization zone. It is also possible to use a spindle head with XYZC axes with vertical mounting of the motor spindle when processing channels for supplying oil to the ingot crystallization zone.

**Figure 6.** Knurling the inner surface of the mold.
Figure 7. Variant of using a spindle head with XYZCW axes: 3D model (a) and nozzle drilling process (b).

Figure 8. Variant of using a spindle head with XYZC axes with horizontal mounting of the motor spindle: 3D model (a) and hole drilling process (b).

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