Small specialized digital manufacturing in mechanical engineering

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Abstract. The problems of creating small specialized digital industries and their role in mechanical engineering are touched upon in this article. It is emphasized that the use of digital technology and modernization of the equipment of existing enterprises for digital technology can bring metal processing to a new higher technological level.

1. Introduction
The introduction of digital technologies and the creation of modern digital industries is a powerful base for moving all sectors of the Russian economy to a new technological level. This is especially true for the engineering industry, which is a basic sector of the economy and needs support and development today [1].

The prerequisites for the emergence of engineering, including metalworking, to the modern level are the rapid development of drive and computer technology, the development of modern software, which has led to a radical change in metalworking equipment. Equipment becomes flexible, mobile and has significantly wider technological capabilities [2]. A modern machine with numerical control (NC) has virtually no mechanical gears and transmission gear cases. Mechanical transmission of the screw-nut rolling gears remained on the machines, which would soon disappear due to the widespread use of linear and circular motors. Today, all the necessary components of a modern NC machine are produced by specialized enterprises in the form of complete modules. They include digital feed and main motion drives, NC systems, measuring systems, lubrication and balancing systems, cooling and cutting area protection systems, ball and roller guides in the form of finished bearings, etc. The modern NC machine is fully digital equipment with built-in diagnostic systems at all levels and with two-way network support not only for management, but also for work monitoring. Today, machines do not specialize in types of processing (turning, milling, boring), but according to purpose (multi-axis processing of shafts, fittings, crosspieces, body parts). This specialization allows performing almost all types of machining on one machine, including splitting and gear processing. The specific character of the use of digital equipment is absence of the need for adjusters of instrumentation and automation and control equipment and qualified maintenance operators, since all this works is performed by a computer.

The use of modern 3D modeling technologies and end-to-end CAD/CAM technologies importance, which, in combination with modern NC machines with end-to-end network support, make it possible to raise mechanical metalworking to a qualitatively new level, make it almost completely digital from the
beginning of design to the completion of manufacturing, including equipment maintenance, is of particular.

The widespread adoption of digital technology in mechanical engineering entails the creation of modern small digital enterprises with a narrow specialization in products, high productivity, flexibility and mobility. In such circumstances, it is advisable to create joint ventures or subsidiaries of small auxiliary specialized digital industries for the technological tasks of large corporations such as RUSAL, SCEC, ALROS, Russian Railways, Gazprom, etc. The creation of such enterprises allows for small businesses to reduce working capital (mainly raw material costs) and have a guaranteed market for products, while for large corporations it leads to a significant reduction in auxiliary production costs and overall production costs [3].

2. An example of the introduction of digital technology in small specialized manufacturing

An example of a small specialized digital machine-building manufacturing is the enterprise we created, focused on solving technological problems of RUSAL for machining foundry equipment (molds and pallets of various sizes) to produce flat ingots. Figure 1 shows a variant of one of the molds manufactured at the enterprise.

![Figure 1. Crystallizer assembly.](image)

To develop digital technology for processing molds and pallets used in the production of aluminum ingots, the existing equipment of a small metal processing enterprise was modernized. The following machines underwent a complete modernization with the introduction of digital technologies: 6M610F11-23 longitudinally milling machine with digital indication produced by Minsk machine-tool production association, 1988 year of production; 65A80 vertical milling machine with a cross table and digital indication of Ulyanovsk plant of heavy and unique machine tools, 1990 year of production; vertical boring machine with NC 25150PMF4 of Sterlitamak machine tool plant, 1989 year of production, and a lathe with NC 16K20 of Moscow factory "Red Proletari", 1978 year of production.

6M610F11-23 longitudinally milling machine has undergone the most profound modernization. The digital display device was replaced by an NC-110 NC system with support for up to 16 axes (8-DSP, 8-DAC) manufactured by JSC “Balt System”. Thyristor feed drives (X, Y, Z) were replaced with modern servo drives manufactured by BOSCH REXROTH. The main drive uses an asynchronous motor with frequency regulation. Optical rulers on all linear axes are used as a feedback sensor. The lubrication system and hydraulics of the balancing system have undergone modernization. For automatic threading with a machine tap, a special unit was designed and manufactured for installing the encoder in the frontal head drive. The mechanical spindle end head was left unchanged, but the side spindle heads with drives were dismantled. At the attachment point of the frontal head, a three-axis spindle head [4] was developed according to the aggregate-modular principle [5], using two-ring motors (A and C axes) and one linear motor (W axis), manufactured by BOSCH REXROTH. Figure 2 shows the appearance of the machine before and after the upgrade, and Figure 3 shows the modules listed above.
Figure 2. Machine 6M610F11-23: a) before modernization; b) two-axis spindle head.

Figure 3. Modules of 6M610F11-23 machine: a) rotation module 1; b) rotation module 2; c) linear drive; d) motor spindle.

Additionally, for 6M610F11-23 machine drilling and rolling units were manufactured. The drilling unit is designed for drilling holes with a diameter of 0.8 mm in the mold cover for supplying lubricant under pressure and includes a linear drive with a stepper motor, an encoder for feedback on movement and a small motor spindle. The knurling unit is used for knitting patterns on the inner surface of the T-shaped mold. The modernization made it possible to combine two processes in one machine. The first process is a three-axis high-performance machining, which is carried out using the main vertical spindle or horizontal spindle of the end head (power machine). The second process is four-, five- or six-axis machining [6], which is carried out with a high-speed spindle in the head and is designed for high-speed finishing with support for HSM technology.

The appearance of the vertical milling machine 65A80 before and after modernization is shown in Figure 4.

Figure 4. 65A80 machine: a) before modernization; b) after modernization.
As a result of the modernization of this machine, the following work was performed: NC-220 NC system was installed with a digital control channel; modern digital servomotors were installed in the machine feed drive; the asynchronous motor with frequency regulation was installed in the main drive; optical rulers were used as linear displacement sensors; the fourth (removable) axis A from the GF 2152 milling machine is installed; a new cabinet for the machine’s electrical automation is designed and manufactured. The NC-220 NC system allows implementing (depending on the technology adopted) two processes: a three-axis machining process using a vertical spindle (X, Y, Z) and a four-axis milling-turning process (X, Y, Z, A).

The appearance of a vertical boring machine with NC 2C150PMF4 before and after modernization is shown in Figure 5. As a result of the modernization of 2C150PMF4 machine, NC-210 NC system with analog control channels was installed; modern digital servomotors were installed in the feed drive of the machine. In addition to the main DC motor with dual-zone thyristor control, a modern high-speed spindle motor was installed in the main drive, which allows implementing HSM technologies. Optical rulers are used as a feedback sensor on all axes. A device for forced cooling of the lower bearings through the coolant system in the main drive is manufactured.

![Figure 5. 2C150PMF4 machine: a) before modernization; b) after modernization](image)

The appearance of 16K20 NC lathe before and after modernization is shown in Figure 6.

![Figure 6. 16K20 machine: a) before modernization; b) after installation from the head UG9326](image)

During the modernization of 16K20 machine, an NC-220 NC system with a digital control channel was installed; modern digital servomotors were installed in the feed drive of the machine. In the main drive, instead of controlling an induction motor via an automatic gearbox, a frequency converter was installed on electromagnetic couplings. As DOS, optical lines were applied along all axes. Instead of the
obsolete six-position turret with a worm drive, an eight-position turret UG9326 was installed with coolant supplied through the tool.

3. The results of the introduction of digital technology in the modernization of a small machine-building enterprise

In 2019, the machining technology of molds and pallets of various sizes was brought to the digital level; a machining process was developed taking into account the modular principle when using equipment with special aggregated equipment. Digital technology includes the following steps:

- preparation, assembly and analysis of 3D models in the SOLID WORKS environment,
- development of the technological process, simulation of processing and preparation of control programs in the SPRUT KAM environment,
- preparation of necessary equipment and tools,
- transmission of control programs through the network to the machine,
- installation and binding of the part on the machine,
- the processing itself on the machine.

Preliminary roughing of molds and pallets is performed on machines 6M610 and 65A80 depending on the size range of casting equipment in three axial modes 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. Finishing of molds and pallets is carried out mainly on 6M610 machine using a special spindle head with a high-speed motor spindle. The spindle head is manufactured on an aggregate-modular principle using two ring motors, one linear motor manufactured by BOSCH REXROTH. Depending on the technology adopted, various layout options for four, five or six axial versions can be combined.

For the application of HSM technology in the processing of aluminum alloys, the working feed must be up to 10 m/min. At the same time, high precision processing should be ensured in combination with high inertial loads. To do this, the design of the machine has transmission gear cases in the feed drive, which increase the starting torque by 6-12 times, which allows raising the positioning accuracy to a micron level on a large heavy machine. Direct feedback (optical lines in all axes) increases the accuracy of measurements, eliminating errors in the intermediate circuits (transmission gear case, bearings, the transmission itself of screw-nut rolling). To raise the working feed to 6-7 m/min, we used BOSCH REXROTH servo drives, developing up to 6000 rpm at a torque of 52 n*m with a pass band of less than 1 millisecond, which allows maintaining high contour accuracy of processing at high working feed. The main cooling of the cutting zone is carried out by a powerful air stream. At the beginning of processing, when the contour speed drops sharply at the corners and the conditions of chip formation deteriorate, portions of oil are automatically fed into the air stream. The supply of a portion of oil is regulated by the special nozzle and controlled by the valve according to the technological command of the control program, which is automatically generated in CAM system. For finish processing of the pan bath and the inner mold contour in a five-axis version with an end mill with a spherical tooth, special processing strategies are used in CAM system. It allows shifting the contact of the cutting zone to the periphery, that is, the axis of the cutter during operation is not perpendicular to the profile being machined, but at a certain angle, which increases the peripheral processing speed and reduces the possibility of chip sticking.

On NC 16K20 lathe, mechanical processing of the lids for mounting pallets on the plate, fittings for supplying water in the mold, and blanks for stripping in the pallet is performed. On the modernized boring machine 2C150PMF4, holes are drilled and final mechanical processing of the spurs using a high-speed spindle is carried out.

The developed digital technology was successfully implemented and allowed to significantly reduce the total cost of fixed assets and ultimately the organization of production.
4. Conclusion
Small specialized digital industries offer significant advantages over traditional engineering industries. Firstly, the high level of digitalization and automation of production virtually eliminates the influence of subjective factors on the quality of products, so the quality of products is determined by the level of technology and the state of the equipment. Secondly, the integration of equipment is based on an aggregate-modular principle, in which all operations for the manufacture of the product are performed on one machine (turning, milling, drilling, threading and gear processing, etc.). Thirdly, the digitalization of production processes leads to the integration into one profession of a designer, technologist, NC machine operator and instrument engineer.

Thus, small-scale specialized digital manufactures require the involvement of more universal specialists who are directly involved in the entire process from design to manufacturing parts and are completely interchangeable.

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