Digital design and technological innovation in the small machine building sector

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Abstract. Integration of CAD products is the governing factor of technical refitting and enhanced competitive advantage of small machine-building enterprises. The digital support associated with PLM and MES platforms makes it possible to state the beginning of a transfer of enterprises to a new type of production. The primary components of the design and engineering stage are as follows: digital design, automated process preparation, and structural engineering. In this process, the part's virtual copy is the central element of the navigation through the process preparation for production. The digital form of documentation in the PLM platform defines the requirements to start production. Electronic versions of documents are an attribute of project management organization in the team, a condition for rapid modification of the object, and a factor of coordination of work of the whole chain: from the project manager and single operators to stakeholders.

1. Introduction
Convergent use of CAD/CAM/CAPP/CAE ideologies is in its early days, but some of the process components have been widely used by enterprises of all sizes. The accumulated experience and growing expertise allow designing and executing both relatively simple and complex high-technology projects at the level of small enterprises.

2. Design support of production
Digital design and engineering support of production consists of 3D design, automated process preparation, and engineering support of calculations on the basis of CAE platforms. The first stage consists of creation and adjustment of digital copies of all the parts and subassemblies on the basis of a CAD platform. This process is accompanied by the development of respective working drawings depicting the required projections, sections, and cross sections [3]. The associative link between electronic prototypes and types of drawings helps to quickly record all the modifications of the digital version in the technical documentation.

The engineering stage involves specification of the layout, detalization of kinematical connections and composition of the future product based on the principle of unification and the maximum involvement of standard subassemblies.
It is also the time to define physicochemical properties of the materials to be used, refine the appearance and ergonomic parameters. Completion of this stage results in the object's design documentation package with subsequent control of the drawings using an expert-level application. The functions of this module include finding faults and flaws in the drawings, check of standards and dimension chains before the documentation may be used in production [4].

The parametrization technique allows obtaining parts of a similar configuration using a single prototype. Forming elements are added to design and technology databases for use in future projects. See an 3D-modeled electronic copy of the "Base" part of an optoelectronic device in figure 1. The software code allows viewing the virtual layout of a designed object in 3 dimensions and various projections, giving it a photorealistic image in accordance with the assigned material to tentatively assess engineering, ergonomic, and design solutions (figure 2).

Figure 1. An electronic copy of the "Base" part.

Electronic copies of assembly units and the whole object help to reveal and eliminate collisions, rule out design flaws, and set tolerances on the basis of the principle of interchangeable parts of a structure. In small machine-building enterprises, 3D design reflects the policy of digital formats in the economy and serves as one of the foundation stones of evolution of production of a new type.

Figure 2. An electronic model of the optoelectronic device's module.
An exploded parts list is drawn up for the purpose of visualization of the structure, assembly and disassembly of the object's modules. The CAD platform's software allows exploding the structure into modules and present the result in an exploded view (figure 3). The result must be quickly editable and graphic. At the last stage of the engineering part, the electronic list is drawn up [5].

Figure 3. An exploded view of the optoelectronic device's module.

3. Technological support of production

The next stage, i.e., process preparation for production, involves automated design of the part production technologies on the basis of a CAPP platform: operations of machine processing and assembly of units and the whole structure. Developers ought to fulfill the part and structure manufacturability conditions [6, 7]. In the process of operation, the CAPP platform interacts with standard, group, and single operating procedures. These are the principles followed to modernize the existing and develop new part manufacturing technologies taking into account the possibilities offered by the available equipment, assign instruments, choose materials and shapes of workpieces, calculate labor indicators, and determine required qualifications of the operators.

Multi-purpose, structured and constantly growing data banks ensure automated support of the process preparation of production [6, 7]. This stage involves design of new technological processes, determination of additive technologies, modes of machine processing and heat treatment, the order of assembly of subassemblies and the structure in whole.

The software for metal-working machines and centers with a digital control code is developed in specialized applications. Interaction with a CAM platform implies choosing the tool assigned in the CAPP databases, finding the optimal trajectory of the cutting tool, as well as simulating the forming process of the given object. Functional possibilities of such a platform allow estimating the time spent on each machine operation and calculating the total metal working time [4, 5, 7].

Machine processing simulation with the cutting tool trajectory imitation taking into account movements of all the actuating and ancillary elements, as well as of the tooling, ensures there are no errors and collisions in the control software. The back-end setup provides a finished part processing software product for a given digitally controled machine column. Simulation of the cutting tool
trajectory for a turning operation within the process of production of the "Shaft" part in the CAM space is given in figure 4.

![Figure 4. The "Shaft" part processing simulation.](image)

### 4. Engineering support of design

Engineering analysis of parts and structures is based on studying the object's stress–strain state by means of computer simulation. This allows predicting reliability of the given parts and the structure in whole both in the standard operating mode and in extreme conditions. Possible types of analysis include the following: calculation for statically loaded parts and subassemblies, modal diagnostics, and thermal deformations [8, 9]. The result of simulation of the water flow in the event of unstable UV treatment tank filling is given in figure 5.

![Figure 5. Unsteady water treatment tank filling flow movement visualization.](image)

The calculation results in a graphic report depicting the object's shape after the study, distribution of velocities, pressure, forces, and displacements supplemented with a color chart with parameter values. The color legend helps to define the zones of the maximum values of the study parameters and draw conclusions as to strength or other characteristics of a structure [8, 9].

The result of experimental static loading of the "Body" part is given in figure 6. It helps to reveal dangerous areas, sections and the maximum deformations of the structure under consideration, as well
as the factor of safety. The color legend helps to visualize simulation results and allows drawing a conclusion as to the part's operability [10, 11].

Figure 6. The distribution of normal stresses in the "Body" part.

5. Design support in virtual reality technology
Use of virtual and augmented reality (VR/AR) technologies—a source of new technological possibilities—is an innovative sphere of digital design. Being in the virtual reality and interacting with the 3D object, the designer gains an objective impression of the project's maturity, can check dimensions of the subassemblies of interest, identify faults and flaws of the layout. The VR technology allows evaluating serviceability and usability of the product, as well as whether it is comfortable. A visualization fragment of a crane cabin imported to a VR system from a CAD platform is given in figure 7.

Figure 7. VR view from the crane cabin.
The use of inverse kinematics in VR/AR systems is accompanied by full control of position of all human body parts and use of tracking systems to reach a higher level of preparation and management of manufacturing processes.

The VR technology helps to largely dispense with the stages of building a full-scale mockup and improve safety of manufacturing process when developing a new product. It enables perfecting and controlling all the technological operations involved in the processes of production and assembly of a product.

The interaction of digital machine-building products is reflected in the PLM platform, which forms the product tree. The structure contains models, drawings, technology descriptions, accompanying documents, and supporting information. In the created project's data bank, the product is saved as a virtual prototype linked to all the parts, subassemblies, and technologies accompanying the development process.

Digital design and support allow modifying structure elements with product configuration management options. These are operated by the PLM platform, where the product tree is formed as an object structure linked to all the components of the structure and the respective production processes. Implementation of a project in the common information space of technological and engineering services is one of the conditions of a digital enterprise. The digital document package formed in the PLM platform constitutes the first stage of production and the condition of future modifications of the product, defines the project group's work activity management rules [12], and serves as the means of coordination of all the links of the manufacturing chain. This offers powerful possibilities for industrial enterprises to implement innovative technologies and new structural and organizational practice principles [12].

The report [13, p. 8] describes a new approach to measuring the real impact of the digital economy, which, according to the authors, "reflects the value of the accompanying digitalization effects" and "the ensuing direct and indirect value." Digital economy management requires coordination of interests of all the social and public groups interested in the development of the parties, aggregation of organizational, labor, and financial resources, as well as joined effort of businesses [1, 2, 13]. The comprehensive approach to the transition of production to the digital space is premised on the integration of both technical and organizational and economic, social, and psychological aspects.

6. Conclusions
Penetration of digital technologies into enterprise activities is reflected by introduction and active use of CAD/CAM/CAPP/CAE, ERP, and PLM systems. The use of high-technology software platforms is a characteristic feature of the modern pattern of development of enterprises of a new type, results in higher labor productivity, faster introduction of new types of products, and improved consumer properties of such products. A stronger role of digital technologies is required not only in the production sphere, but also in the marketing policies of enterprises to improve their effectiveness and potential. Digital design reflects the technical part of the problem of transition of small enterprises to virtual production on the basis of innovative solutions and development of a manufacturers' information space.

The digital field of small enterprises is a constituent part of the global information space, and all the innovative technologies are reflected in it. The digitalization policy manifests itself on all the levels of the person–society–material production interaction.

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