Design and Application of Technological Complexes in Digital Production

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Abstract. The analysis of the current state and prospects for the development of additive technologies of computerized production suggests a new paradigm in its evolution - “Industry 4.0”. It is shown that the processes of additive production, in addition to analyzing the technology for obtaining a product, require the development of information technologies for their modeling. For layered manufacturing technologies, an algorithm is proposed for splitting the product into layers of different thickness, taking into account the angular cutting of their edges. The computer design of the formation of the layer and the subsequent assembly of products of complex geometry in an automated technological complex is considered. The design of the processes of sheet cutting and layer-by-layer assembly, with examples of the formation of products of complex geometry, is considered, taking into account the use of a 5-axis manipulator in an automated cutting complex.

Introduction
Improving the efficiency of production activities is the creation of complexes of technological, transport, energy, and information machines based on new additive technologies and increasing the productivity of those already used [1-4].

Currently, a new era of production is emerging - mass customization, characterized by the fact that the consumer acts as a designer and engineer. Now, at the request of the consumer, you can directly monitor and control, as well as change the production process. As a result, in the system analysis of the growth of the efficiency of technological complexes, it is necessary to count not only the specific technological complexity (cost) per product, but also the costs throughout the product life cycle, especially related to its customized marketing, design, operation, utilization and reduction of various logistic supplies [5-8].

Production and targeted delivery of a customized product, taking into account the external and internal logistics of the enterprise (including virtual), can be supplemented with the future stages with a forecast for the future, which is often associated with the new paradigm of intellectual production called «Industry 4.0». This term was proposed by German companies at the Hannover Technology Exhibition in 2011 to mark the beginning of the “era of the fourth industrial revolution” associated with the Industrial Internet of Things [9-12].

Development of technological equipment using energy flows
The development of technological complexes begins with an analysis of the concept of a mechatronic system with two control loops, through direct communication with the external environment and feedback on the results of diagnostics of the state of the control object [6, 7, 13, 14].

The choice of energy flows and materials for the layer-by-layer synthesis of the product is carried out depending on the properties of the materials or their compositions, the geometric characteristics of
the surfaces, and their accuracy. At the same time, special attention is paid to the focusing or distribution of flows in space and time.

An analysis of the attainability of the accuracy of surface formation from the standpoint of the influence of the power density of the applied concentrated energy flows (Fig. 1) allows us to recommend a number of energy sources for use in cutting equipment [2, 3, 15, 16]. The following technological sources provide an almost continuous power density range: gas flame and plasma arc; welding arc and spark discharges; continuous and repetitively pulsed lasers. Of particular interest are flows of abrasive particles, which, when interacting with a high-pressure jet, interact with the surface, are processes similar to wear and chipping under intense friction and running-in.

![Figure 1. Using concentrated energy flows in cutting equipment](image)

This caused, depending on the tasks to be solved, quite active use in cutting equipment: gas-flame, plasma, electric-spark (erosion), laser energy sources.

The choice of sources for cutting equipment is determined by both the thickness and the material of the sheet blanks, and the processing accuracy.

Mechatronic technological complex (Fig. 2) implements a direct connection in controlling the flow of energy or material synthesizing the product in layers, and feedback on the state of the formed layer or the surface of the formed product [7, 16].

A graph of tuples of various types of processing of the designed technological equipment is considered and the imposed connections are analyzed: mechanical and electrical (drives and sources), electronic and software (controls and managements) in the mechatronic system [7, 16]. As a result, the source drive is implemented as a multi-axis manipulator, and the complex itself and its equipment are a mechatronic technological system (Fig. 3).
This technological complex allows both cutting and subsequent layered sheet assembly of the finished product by welding along the contour with a plasma welding head of the Kjellberg company (Fig. 4).

**Figure 2.** Block diagram of the mechatronic system

**Figure 3.** Technological complex of plasma cutting material with a manipulator for cutting and cutting the edges of the workpieces at an angle
Computer design of sheet cutting and layer-by-layer assembly of products

To improve the quality of the surface of the formed product and reduce the duration of the prototyping and production processes from the standpoint of the types and shapes of the blanks of the materials used, rational division into layers was considered, taking into account the assessment of surface quality depending on the shape of the product. The analysis of partitioning in various methods of layer-by-layer synthesis provides a choice of the most rational processes of prototyping and production of a specific product [3, 16].

The division into layers of the same thickness and different angles of inclination of the edges inscribed in the geometric profile (Fig. 5, a) and the uneven thickness of the various layers (Fig. 5, b) is considered. Splitting directly affects the geometric parameters of the surface quality (Rmax, Rz, Ra, etc.).

The calculation of the total number of layers allows us to estimate the efficiency of the process chosen for the layer-by-layer synthesis of a product of a given shape by one of the proposed methods.

Verification of the layer-by-layer synthesis model makes it possible to verify the satisfaction of the requirements for the geometric parameters of the quality of complex profiles embedded in the computer model of the product.

Regulation of the layer thickness and the angle of "cutting" of its edges allows you to control the geometric parameters of the quality of a complex profile surface and make adjustments to the initial choice of the additive production method.

Checking the adhesion of product layers in some cases requires, in addition to determining the area of their overlap, also an analysis of the relief of a flat or complex profile surface. The latter option is usually used when applying shells or coatings on a layer of "grown" product.

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Conclusion

Thus, the analysis of the current state and prospects for the development of additive technologies of computerized production suggests a new paradigm in its evolution - “Industry 4.0”. As a result, the concept of a “digital factory” is formed and detailed, in which additive technologies are the defining element of the system, including advanced subsystems: 3D design and production and consumption management, starting from modeling a product, its materials and components in accordance with new technological capabilities and ending production and operation of a functionally oriented customized product.

The analysis of methods for obtaining machine parts without formative tooling showed that the processes of additive production require, in addition to studying the technology of obtaining products from structural materials, also the development of information technologies for their modeling. To ensure high accuracy of the geometric shape, an algorithm is recommended for splitting the product into layers of different thickness, taking into account the cutting of their edges at an angle.

The design of the processes of sheet cutting and layer-by-layer assembly, with examples of the formation of products of complex geometry, is considered, taking into account the use of a 5-axis manipulator in an automated cutting complex.

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