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Development of an Algorithm for Adaptive Control of the FDM Printer Printing Process

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***Abstract*— The specificity of the tasks assigned to 3D printers leads to the fact that the cost of each manufactured part, as well as the entire final product as a whole, largely depends on the level of debugging of the printing process. Today, FDM printing is characterized by the occurrence of both system and random deviations in the shape of the manufactured parts, which leads to a loss of time, production resources and rejection of the manufactured part. Manufacturing enterprises are interested in increasing the cost-effectiveness of manufacturing parts by printing. Solving the problem of increasing repeatability by introducing an adaptive system for controlling the printing process will reduce the production time of products, eliminate the participation of personnel in the manufacturing process of the part and reduce the cost of production of products. The work presents the algorithm of operation of the adaptive system for automated control of the process of printing parts on printers equipped with an optical production control system.**

Keywords - Additive technologies, automated control, intelligent control, FDM-printing, polymer materials, optical control, control algorithm, quality improvement, non-destructive control, control program, product properties.

I. INTRODUCTION

To date, the practice of using details of a complex form has become widespread. In the best way, extrusion printing devices cope with the task of prototyping and manufacturing labor-intensive tooling elements and structures. Additive technologies are most widely used to create full-scale samples of products and finished parts of one- or small-scale products. Additive manufacturing features allow the production of desired products from a wide range of materials, which leads to rapid expansion in the fields of application of such technology. The pace of development of methods of additive production of parts suggests that in the coming years their goal is likely to focus on the production of large-sized products. The extensive use of layer-by-layer fabrication technologies can lead to a significant increase in the economic effect of the production of parts and, as a result, of the final product. One of the most common methods of manufacturing additive products is the FDM simulation. This method is a process of layer-by-layer deposition of the final part material using the yarn or granules of the selected polymer as the starting material. This technology most accurately reflects the key advantages and disadvantages of additive part growing, as a result of which it is of great interest as a technique available for debugging and improvement.

II. OVERVIEW OF THE SUBJECT AREA

As a result of the extensive use of FDM printing technology, it was found that each individual part production cycle has a significant risk of deviations. The nature of these errors can be very different: errors can be systematic and random. In any case, the occurrence of such anomalies usually leads to the abandonment of the part and entails the re-production of the product. The lack of the ability to ensure the equally successful production of parts of different configurations leads to the inability to debug and create a universal type of control programs that can eliminate all arising deviations [1]. The most successful solution to the problem of increasing the probability of successful execution of a part is the use of an adaptive system for automated control of the printing process. The implemented system should be able to analyze the environment parameters in the working area, respond to changes in the process of laying the thread and working out movements by drive devices, as well as be able to correlate the actual mode of laying the material with the calculated one and take measures to eliminate errors or change the mode of operation.

A significant part of modern FDM printers has an identical device, ranges of applicable materials and part production modes, as well as a set of software and hardware that controls the printing process. Matching these properties allows you to find a universal solution for optimizing the production process. The development of an effective printing control algorithm to optimize the production process on FDM equipment will expand the scope of this type of additive technologies, as well as allow it to be used in the production of serial products. With the widespread introduction of an adaptive control system, the cost of parts will decrease with an increase in the probability of successful production, which will lead to a significant increase in the economic effect of producing the entire product.

III. MODEL OF PROPOSED SYSTEM

The article offers a comprehensive solution for automation of the printing process, available for the use of a wide range of types of printing devices using common control software. Proposed relationships of executive and computational elements of system allow to vary methods of initial data setting, criteria for evaluation of printing correctness and types of output control commands. The problems of modern production are most solved thanks to the proposed set of control tools that form an adaptive system for controlling the printing of the production site.

A. *Purpose and Tasks*

The solution of the problem of increasing the level of error-free production of products is of interest to industrial enterprises of a wide range of production directions. In this regard, it is possible to distinguish the goals and set the present development.

The purpose of this work is to develop an apparatus for controlling an adaptive system for automated optical control of the manufacturing process of parts produced by FDM printing. Also, an important object of the study is to propose a structure of the relationship between control and actuating elements of the production complex, which includes a printing device, computing devices and means for communicating blocks with each other.

Tasks facing the Automated Print Process Control System:

- development of a structural scheme of the system;
- development of communication principles and interconnections of system elements;
- proposing a method of combining used units as part of a control system;
- proposing a decision architecture on the admissibility of the current trajectory;
- development of a set of tools and tools necessary for the self-sufficient functioning of the system;
- proposing a list of possible process anomalies and deviations to be corrected;
- evaluation of applicability and scalability of the proposed system;
- proposing a method of combining control programs of individual devices within a single control center.

B. *Scope of application of the proposed printing process control system*

The process of manufacturing products by FDM printing is characterized by the variability of printing conditions from part to part, therefore, the control system should be able to record changes in medium parameters and corresponding deviations in material filament laying. For an adaptive automated control system, it is important to have a wide range of commands and scenarios that can meet the largest number of print deviations that occur during production. Also, the system will be appropriate in cases where the algorithm for determining print errors and methods for taking corrective actions do not depend on the properties of the material and the print mode. The software and hardware complex included in the system must meet the production and technological requirements of the production area and computing equipment serving the printing device.

The main limitation in the applicability of this type of control system is the types of printing devices that result in difficulty or limitation of optical tracking of the manufactured part. Examples of such devices are printers with a non-orthogonal arrangement of the axes of movement of the print head or printers with large print heads, which make it difficult to track the placement of the thread.Structure diagram of functioning of control system

Device of proposed system represents modular structure including technical means of printing control, optical registration of thread movement, sensors of medium parameters fixation in working area, set of hardware and software for information reception, processing and transmission and creation of control commands for change of printing process. Fig.1 shows a proposed diagram with software functionality combined in a single computing device.

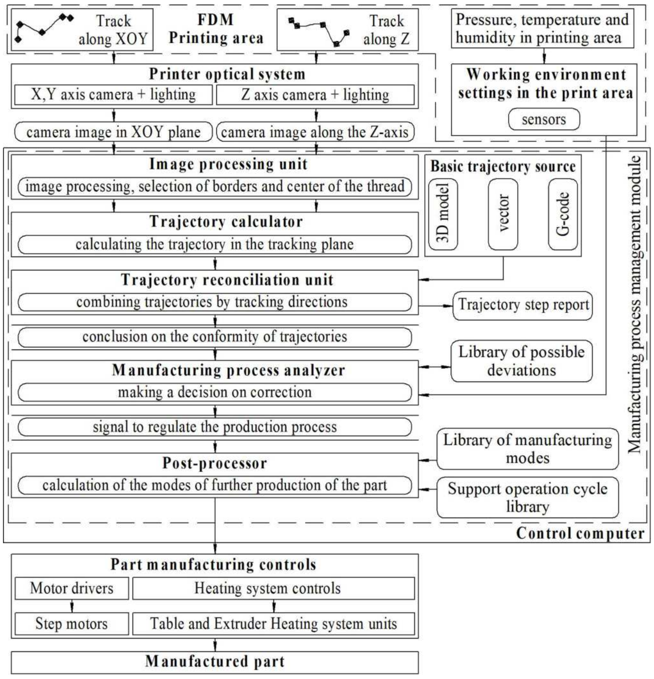

Fig. 1. Structural diagram of the adaptive automated optical control system of the FDM printing process based on the proposed control scheme.

In accordance with the scheme, cameras with their own lighting sources installed in the vicinity of the working area of the printer allow to obtain an image reflecting the progress of laying the material thread in the XOY and ZOY planes relative to the center of the table. Thermometer and pressure gauge installed inside working zone allow to obtain readings of medium parameters in printing zone.

The signal received from the cameras is supplied to the image processing unit. In this step, the image is processed. On the basis of the algorithm for determining the boundaries of bodies, the boundaries of the laid thread are selected and the center of the laid thread is calculated at each iteration of control [2,3].

The trajectory calculator determines the offset of the center of the placed thread relative to the previous calculation step, thus creating a trajectory from the application of the thread.

In the trajectory matching unit, the calculated path of the laid thread is compared with the calculated trajectory determined at the stage of compiling the main production process of the part. The basis for matching may be a 3D model, a vector image of the path of movement of the printhead through the layers of the part or control program for printing in the form of a G-code [4]. The completed reconciliation step is reported in the part progress report.

Based on the data on the state of the working environment in the printing area, the results of comparing paths and the library of permissible deviations in printing, a decision is made on the occurrence or absence of critical deviations in the production process of the part. In the case of a critical deviation, the analyzer determines how to correct the error based on typical correction algorithms.

As a result of the evaluation of the current stage of production of the product, a decision is made on the application of corrective commands. The change request of the assigned control program is sent to a post-processor, which calculates the most optimal scenario for correction of deviations and creates a new control program calculated based on libraries of printing methods and algorithms for execution of auxiliary processes, correcting deviations of the part shape.

Control signal from post-processor is sent to control drive printing mechanisms. Execution of the commands that are executed by the printer drives allows you to adjust the print production process or suspend the production process [5].

C. Operation algorithm of the print mode control unit

The operation of the error detection system and the decision on the need to change the manufacturing mode of the part is based on the product manufacturing process analyzer. This element is a set of combined blocks necessary to study data on the progress of the yarn laying process, the relationship of this information with the calculated production modes and the trajectory, decide on the assignment of corrective actions, as well as compile commands and requests necessary for the post-processor to form control commands for mechanical printing controls.

The key units of the analyzer are:

- a unit for setting a tolerance criterion for detected deviations;
- block of relation of working area medium parameters at the current control step and deviations of thread laying coordinates;
- a deviation matching unit with a library of possible deviations;
- a trajectory admissibility decision block considering checking the combined total deviation data at the current control step;
- a block for making a decision on the nature of corrective actions;
- a message block with a post-processor.

The task of the manufacturing analyzer is to determine the correspondence of the trajectory of the initially specified and to take measures to eliminate the error in case of deviations and to create a control command for the post-print control processor to implement a set of technological operations necessary for the correct continuation of the printing process. For the most efficient operation of the analyzer, libraries of possible deviations in the printing process and typical scenarios suitable for eliminating popular types of deviations are used. If a deviation is registered that is not specific to the deviation library, the decision is made to initiate corrective actions. At that, all data of geometric deviations, information about environment parameters and a group of standard commands for elimination of anomalies are taken into account.

Visualization of the set of functional elements included in the printing process analyzer is shown in Fig.2

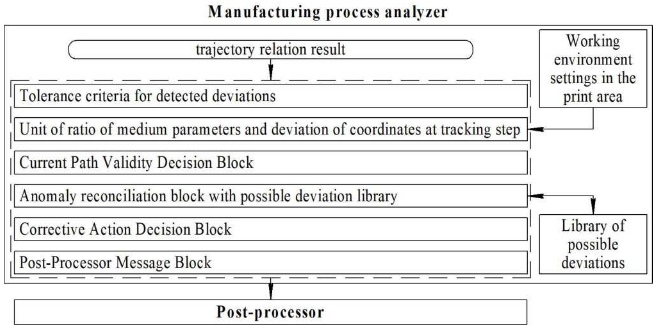

Fig. 2. Function elements of the printing process analyzer

The print process analyzer implements a linear algorithm based on commands from previous modules of the system, as well as attached libraries and repositories.The results of the trajectory ratio coming from the reconciliation module pass through the evaluation section to the given criterion of tolerance of deviations. The decision to satisfy the criterion and the admissibility of the trajectory for continuing printing leads either to the continuation of the original printing mode or to a study of the deviation for compliance with library precedents. Depending on the correspondence, a request is created to generate typical corrective actions or specialized commands. The received command from the reconciliation section enters the exchange unit with the post-processor. Here, a control request is created for the post processor, which contains the information necessary to reassign the production mode based on the decision made on the suitability of the trajectory. Analyser decision algorithm is given in Fig. 3.

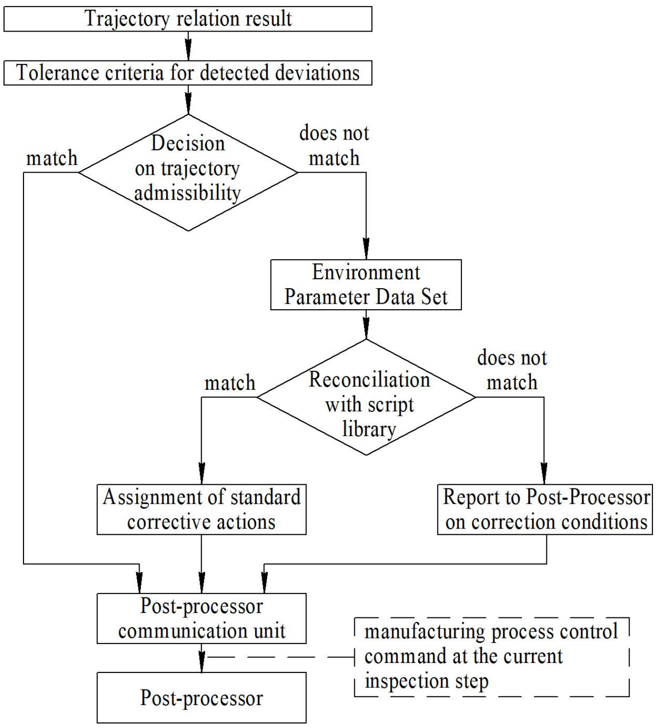

Fig. 3. Flow chart of the printing process analyzer

In view of the large number of structural connections in the decision-making process, the time for making the final decision and the generation of the control program for the actuators may take more than one step of the stepper motors.

In this regard, a rational solution will be to summarize the results of the analysis of the section of the trajectory corresponding to several steps of the engines. This solution will allow you to explore the trajectory without using more powerful and expensive computing equipment and not reduce the high rates of stacking of the material thread.

D. *Evaluation of applicability and scalability of the proposed system*

The optical control system implemented on the basis of the proposed control algorithm avoids most defects in the printing of the part, regardless of the cause of the deviations. The variability and the ability to fine-tune the criteria for compliance of the calculated and actual yarn laying trajectories allows you to change the accuracy requirements for deciding on the application of corrective measures. The set of commands and auxiliary processes for re-setting the manufacturing process eliminates the need for human participation in the part manufacturing process.

The main limitation in the application of the proposed control system is the speed of computing devices of the control computer and means of transmitting data between nodes. Depending on the amount of RAM, the degree of optimization of the computation and data exchange algorithms, the present system may use as control data a set of information obtained at a certain time interval, and not from each step of the stepper motor. Since the speed of filament stacking by the printing apparatus is limited, the most real solution to the problem of trajectory backlog and matching is to discretize the data and introduce a control step sufficient to detect the error in a timely manner and take appropriate measures to eliminate it.

The use of the proposed automated printing control system is advantageous in cases where the production cost and production time of each unit of product exceeds the costs required for the equipment of the production site. Optical control technology allows scaling of the proposed production method to the level of production sites. The system management architecture allows you to include new tracking and actuating devices in the form of parallel calculation cycles on one control computer. The main condition for the efficiency of multiplying the production capacities of the technological site in the enterprise is the ability to provide a sufficient reserve of computing power for processing information and exchanging signals of the entire group of control devices [6].

IV. Conclusion

A print management system based on the proposed control algorithm will allow you to change the purpose of FDM printers as production devices. Adapting the process of printing parts to the conditions of large-scale application of this technology will expand the use of additive technologies. The introduction of automation of the manufacturing process of the part also provides a subsequent increase in productivity in the printing apparatus. The proposed system can also help to master multi-component printing technology, as well as contribute to the development and subsequent use of materials and types of printing devices that meet higher printing speeds.

The main achievement of this solution is the reorientation of the purpose of existing devices and the involvement of their production capacities in the production of serial products. The gradual improvement in the quality of production of printers, printed materials, as well as control software will allow in the coming years to redefine the distribution of production tasks between traditional production methods and extrusion printing technologies.

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