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Extending the Functional Capabilities of NC Systems for Control over Mechano-Laser Processing

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Abstract—The universal architecture of NC system to control mechano-laser machines tools is offered. The specific character of application of NC systems for various methods of laser processing is shown: laser sintering, engraving with a low frequency impulse emission. As an example of use of NC systems to control complex systems of the mechano-laser equipment the machine representing processing center, realizing hybrid technology is considered: machining in combination with the laser.

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1. INTRODUCTION

At present, construction of NC systems actively uses mechanisms based on open modular architecture [1]. This principle has been used in the creation fo a flexible, easily adaptable to control various types of technological equipment, NC system AxiOMA Ctrl developed at MGTU "Stankin." One way to adapt the NC system AxiOMA Ctrl is a control system for laser technological complexes [2].

Active use of laser equipment at present is caused by the fact that this technology lets one achieve high processing rate while preserving high positioning accuracy. Over the last several decades, industrial lasers have come from cumbersome low-power devices with low performance factor and nearly uncontrollable emission that one would need a complex system of lenses and mirrors to transmit to small scale and powerful devices that transmit their emission over a thin flexible optical cable immediately into the processing zone with performance factor up to 25% and with several different power steps that can be contrlled.

With this class of technological equipment, one can solve various problems, including laser marking, three-dimensional and flat engraving, cutting metal sheets, and complex mechano–laser processing. layered synthesis technologies that let one quickly create prototypes for future items with characteristics close to the original have also been rapidly developing recently [3].

To improve processing efficiency and precision, one uses modern NC systems that allow for a combination of the laser complex with axis drives which opens up a possibility to process raw materials of larger sizes.

2. CONSTRUCTING A MODEL FOR A UNIVERSAL NC SYSTEM FOR MECHANO–LASER PROCESSING

In mechano–laser processing, to move the laser ray on a plane the following control methods can be used:

- linear/step drives that get motion parameters immediately from the NC system's interpolator;
- devices implementing external control over the motion. Such devices get lists of motion commands and process the ray's motion in the working field by themselves.

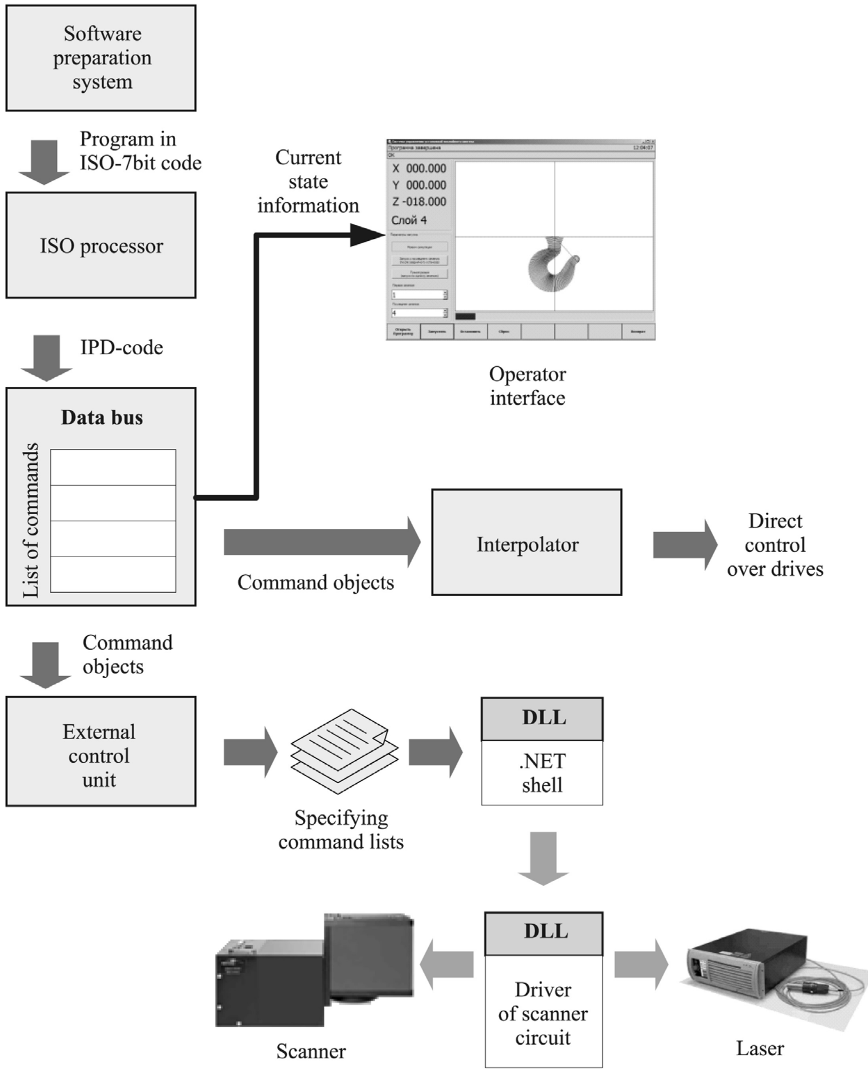

Fig. 1. A structural scheme of a NC system that uses external control devices.

Thus, a universal architecture for a NC system must allow for simultaneous application of both control methods.

One of the most widely used devices that implement external control over the ray's motion are galvanic laser scanners (or deflection systems for the laser ray). Construction of modern scanners lets them function reliably for laser power up to 500 W, and accessory lenses increase the scanning area up to 500×500 mm with precision up to 2 μm. The scanner can ensure larger average motion speed since deflecting mirrors have small inertia.

As a typical scanner we consider FOCUSSHIFTER, a precisional three-axis galvanic laser scanner produced by Raylase that positions the laser ray spot into any place on the working plane (specified with two angles). This device is controlled via an interface circuit whose driver accepts a certain set of commands to control the motion and parameters of the laser. The control process with a scanner via user software looks as follows:

- the interface circuit's buffer receives a list of commands via driver functions; the commands may include motion along a straight line or a polygon, setting motion parameters (delays, speed etc.), and setting laser emission parameters;
- processing of a list of commands is initiated;

- when the entire list has been processed, the next list is loaded, and the process is repeated until the entire program is over.

Thus, control software does not have to work in strict real time and provide direct control over the motion. It merely has to send the commands to the controller circuit that by itself provides all immediate control functions over executive devices (deflection units, focusing units, and the laser itself).

To control the scanner and similar devices, an NC system together with a standard interpolator has to implement an external control unit that has the same interfaces as an interpolator but delegates immediate motion control to external devices (e.g., a controller or a scanner circuit). The general structure of a NC system that implements external control functions is shown on Fig. 1.

In this scheme, the list of commands created by the ISO processor upon interpreting a control program is available both to the interpolator and to the external control unit. We still have a possibility both for direct control over the drives and for scanner control in a single control program. This possibility may be realized as follows:

- when a command to switch to external control mode appears in the control program, the interpolator enters waiting mode, and the external control unit gets a command to launch;
- movement commands are sequentially extracted from the list with the external control unit. Depending on the type of command, the control object is influenced by calling its controller's interface functions, and commands begin to execute after the list has been populated;
- during the execution of the list of commands, the external control unit receives from the object current values of the parameters and transmits them into the data bus (so that the terminal part could update indicators of current coordinates and similar information);
- when the command to exit external control mode appears, the interpolator exits its waiting mode.

Such a structure is universal in the sense that it lets one implement control over various devices inside a single control program and use a single NC system for different laser processing technologies (engraving, layered synthesis etc.) without any conceptual changes in the system architecture [4].

3. CHARACTERISTIC FEATURES OF APPLICATIONS OF NC SYSTEMS FOR LASER PROCESSING CONTROL

3.1. Layered Synthesis Devices

Rapid prototyping technologies (RP) have become an integral part of the process of modern material production. Devices for layered synthesis from powder materials represent a class of RP devices that can be used not only to create prototypes of items at the design stage but also to manufacture ready product with ceramic and metallic powders.

The method is to sequentially apply thin layers of a metallic or ceramic powder in the working areas and then bake it with a scanning laser ray. The resulting item is thus "grown" bottom up.

A small portion of the powder is pressed from the bunker. With a roller, the powder layer is evened around the synthesis zone and compressed. Extra powder is removed into a special bunker. Then, with a laser system the laser ray spot, moving along the processing plane, bakes the new layer of powder together with underlying layers. After baking is complete, the plunger moves down, freeing up space for a new layer of powder material. The problem of contour movement of the laser ray spot in this manufacturing method is solved with a laser system based on a galvanic laser scanner [5].

In creating a control system for layered synthesis tuning, the main problem is to construct motion trajectories for the laser ray spot layer by layer, based on the geometric model of the item being

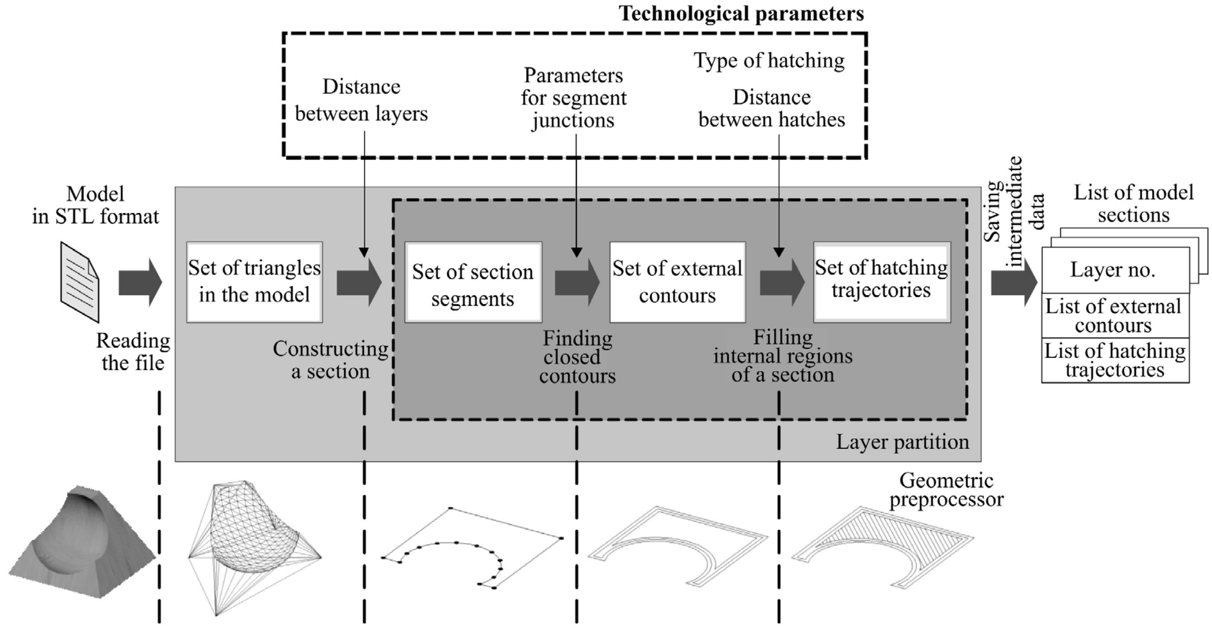

Fig. 2. Generalized operation scheme of the STL preprocessor unit.

manufactured. This problem is solved with a preprocessor that generates a controlling program based on the item's geometric model in STL format.

Basic functions of the STL preprocessor:

- open a file in STL format and check that the model does not contain discontinuities in its surface, double and separately standing polygons; it is also useful at this stage to find common vertices of polygons with some similarity criterion in order to find adjacent polygons and thus reduce the number of facets and vertices one has to store;
- specify parameters of the model's partition: distance between layers, type and distance between hatch lines, number and distance between equidistant curves of traversing external contours of the section and other parameters;
- check functionality of the model's partition with respect to sections. This functionality includes: dissecting the model with a plane; finding boundary contours and constructing their equidistant curves; constructing hatching trajectories for internal regions of a section; automatically finding special zones of the section. Such zones may include, for instance, thin walls in the section or any other areas that have to be processed with technological parameters other than processing parameters for the rest of the item.

A generalized operation scheme for the STL preprocessor unit is shown on Fig. 2.

The preprocessor reads the set of the model's triangles from a file in STL format. Then it constructs a set of model sections by parallel planes. In each section, it finds a set of external contours, and to each external contour we construct several equidistant curves from inside the item in order to make the item's external wall as solid as possible. Then it constructs hatching contours in internal regions of the section that create a dense structure of baked powder inside the item during processing. Output data in the form of the set of section layers of the model is transmitted to the generator of controlling programs [6].

3.2. Engraving with Impulse Low-Frequency Emission

Impulse laser processing is widely used in various fields of industry. A widespread technology for this is volume and planar laser engraving. Among engraving machines, the most popular are

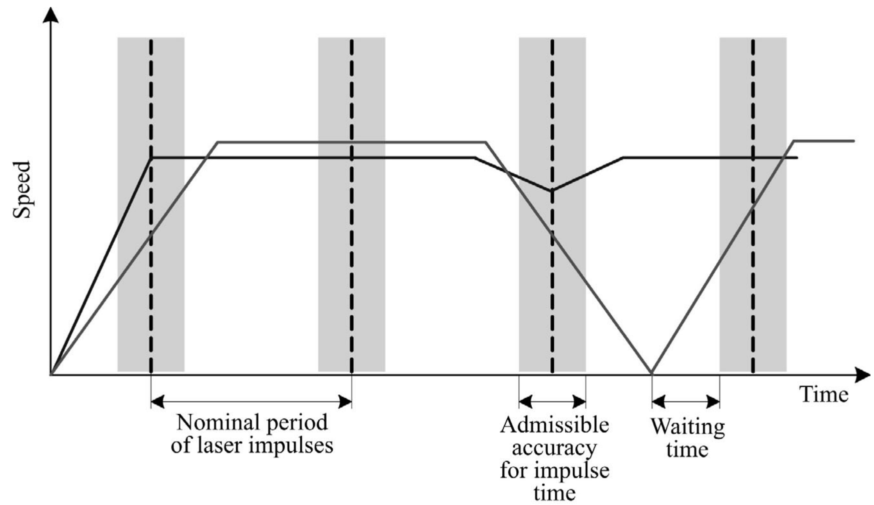

Fig. 3. Motion under the standard and optimized control schemes in impulse laser processing.

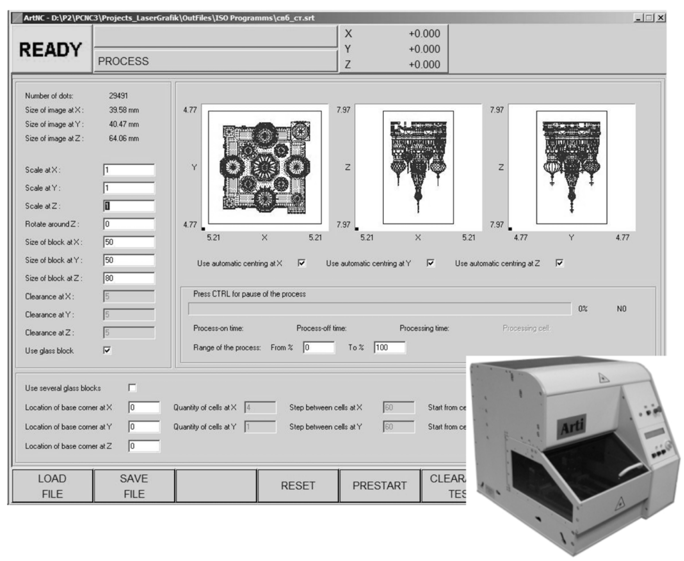

Fig. 4. A compact laser graphics machine produced by LaserGraphicArt and the main screen of the NC system ArtNC adapted for laser engraving.

machines based on a solid state laser that operates in impulse mode with impulse frequency of the order of 30–100 Hz (used for volume engraving in transparent media). The main characteristic feature of the control for such a machine is the need to ensure strict synchronization between laser impulses and raw item motion. The problem is that the frequency of pump lamp impulses must be met up to a certain admissible accuracy, otherwise the impulses' energy will not be distributed equally in time, and the engraving result will be incorrect (for instance, the laser will the miss or "underburn" some points). Thus, after processing a motion to a certain point the NC system must wait for some time before sending a command to perform the laser's working impulse (Fig. 3).

This scheme shows the graph of speed with a regular motion control approach with a lighter line. One can see that a significant part of the item's processing time is wasted in waiting for the next access window. Besides, engraving programs usually consist of a large number of small frames, so the performance loss is very significant.

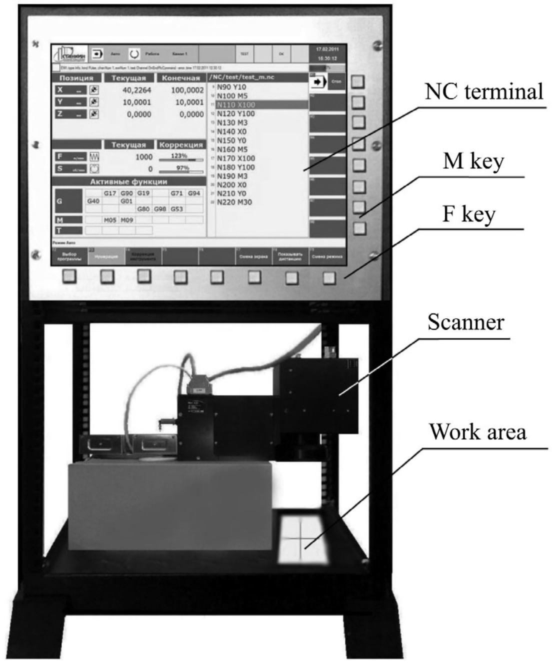

Fig. 5. A testbed for engraving algorithms based on a galvanic laser scanner.

In adapting the NC system for laser graphics machines produced by LaserGraphicArt, the main problem was to improve item processing efficiency while preserving access times for laser impulses (Fig. 4).

Due to this problem, the interpolator of a NC system has to implement a mechanism to adapt the motion to impulse parameters. The motion control algorithm must possess two very important properties: synchronize motion with laser impulses in order to avoid stops in processed points and ensure optimal speed of passing the points depending on admissible acceleration with respect to the axes and other parameters.

Motion synchronization means that the path between two working points must be traversed over a precise period of time defined by the laser's frequency and its admissible error. Impulses of the pump lamps are given by the NC system rather than the laser's clock generator [7].

Before motion begins along another segment of the trajectory, we compute parameters for the acceleration/deceleration profile (shaped as a trapezoid). We first compute the maximal final speed in a frame (using the look-ahead algorithm) and then correct the final and nominal speeds so that the total time of passing over a frame would divide the period of laser impulses. The result shown as the optimized speed graph is depicted with a darker line on Fig. 3. Implementing this algorithm allowed us to reduce item processing time by 30 to 50% as compared to the standard control scheme.

Functionality specific for the interaction with a laser machine is primarily limited to the interpolator that provides basic functionality for controlling motion along a given trajectory. Virtually all computations related to motion parameters occur at the stage of analyzing the command in the acceleration/deceleration unit. The impulse adaptation algorithm is an overlay for the algorithm for finding the maximal admissible speed. A combination of the look-ahead algorithm with the algorithm that tunes to laser frequency lets us find the optimal speed mode. The parameters used here, such as the laser's frequency and its admissible error, maximal accelerations with respect to axes etc., can be easily tuned by the machine's tuner which lets us find the optimal tradeoff between performance and processing quality experimentally. If we use a galvanic laser scanner or some other focusing device that implements its own ray motion control algorithm, one can tune the acceleration/deceleration parameters similarly, but the computed parameters are not used to process the contour with an internal system interpolator but rather are sent to the scanner's interface device. Figure 5 shows a testbed with a galvanic laser scanner used to test laser engraving algorithms.

3.3. Complex Machines for Mechano-Laser Processing

An NC system for controlling complex mechano-laser equipment has been implemented during our work on the "Mechlaser" project. The machine is a multioperational processing center that implements a hybrid technology: mechanical processing together with a laser.

The equipment can be used in generating geometry and final processing of press forms for pressurized casting. One need complex processing in dealing with such items, so in our operations we use five-coordinate mechanical processing. Then the blank is subjected to final processing under laser emission. Besides, laser emission can put special covers on the item's surface and temper individual areas.

Mechanical processing is implemented in the machine with control over six coordinates, two of them for moving bridge-type guideways. The machine also has a rotating globe table that provides one-hit capability for complex items.

The machine also uses a laser; during mechanical processing, the laser is closed in a special section located on the instrumental head. A characteristic feature of laser emission is the possibility for a short-time powerful heating on a small area. By varying the power, area of focusing spot, time of action, and supply of various gases and materials into the heating zone, one can perform a number of various operations: cutting, welding, spattering, polishing, thermal processing, deep perforation, drilling high-impact materials of turbine blades, engraving, three-dimensional removal of a metal layer by vaporization and many other [8].

The "Mechlaser" machine has a laser produced by the "IRE-Pole" company (Fryazino) whose design is based on Russian developments in this field. It combines the advantages of two cutting edge laser technologies: an active optical fiber with core made of rare earth elements and high-power multimode for semiconducting pump diodes.

We have to note that a machine operating with hybrid technology presupposes the use of a wide variety of additional technological equipment necessary both for mechanical processing (pumping station for the rotating table mechanics, a water cooling system for the engines, bearing lubrication system, tool storage magazine, coolant, control systems for the tool and the item, a conveyor belt for removing shavings) and for laser processing (deflector, laser focusing head, air preparation unit, a water cooling system for the deflector and the laser). All this equipment imposes additional constraints on the control system. It must be sufficiently reliable, must have many inputs and output. It is also possible to use several industrial logistics complexes that autonomously solve control problems for additional mechanical and laser processing equipment connected with each other on a master-slave basis.

4. CONCLUSION

The open architecture that underlies the NC system AxiOMA Ctrl, together with modern development tools lets one create a flexible, easily adaptable control system for laser technological complexes. The proposed model for a universal NC system for mechano–laser processing lets one organize control over virtually any executive devices inside a single control program by introducing pluggable external control units. This lets us reduce development time and time to market for control systems for various kinds of processing with lasers (laser sintering, engraving, hybrid mechano–laser processing).

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