Lecture Notes in Mechanical Engineering

Volodymyr Tonkonogyi ·
Vitalii Ivanov · Justyna Trojanowska ·
Gennadii Oborskyi ·
Ivan Pavlenko *Editors*

Advanced Manufacturing Processes IV

Selected Papers from the 4th Grabchenko's International Conference on Advanced Manufacturing Processes (InterPartner-2022), September 6–9, 2022, Odessa, Ukraine

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Preface

This volume of Lecture Notes in Mechanical Engineering contains selected papers presented at the 4th Grabchenko's International Conference on Advanced Manufacturing Processes (InterPartner-2022), held in Odessa, Ukraine, on September 6–9, 2022. The conference was organized by Odessa Polytechnic National University, National Technical University "Kharkiv Polytechnic Institute", Sumy State University, and the International Association for Technological Development and Innovations in partnership with Poznan University of Technology (Poland).

InterPartner Conference Series promotes research and developmental activities, intensifying scientific information interchange between researchers, developers, and engineers.

InterPartner-2022 received 91 contributions from 15 countries around the world. After a thorough peer-review process, the Program Committee accepted 55 papers written by authors from 13 countries. Thank you very much to the authors for their contribution. These papers are published in the present book, achieving an acceptance rate of about 60%.

We want to take this opportunity to thank members of the Program Committee and invited external reviewers for their efforts and expertise in contributing to reviewing, without which it would be impossible to maintain the high standards of peer-reviewed papers.

Thank you very much to keynote speakers Dr. Slawomir Luscinski (Kielce University of Technology, Poland), Dr. Justyna Trojanowska (Poznan University of Technology, Poland), and Prof. Oleh Onysko (Ivano-Frankivsk National Technical University of Oil and Gas, Ukraine).

The book "Advanced Manufacturing Processes IV" was organized into seven parts according to the main conference topics: Part 1 – Design Engineering, Part 2 – Manufacturing Technology, Part 3 – Machining Processes, Part 4 – Advanced Materials, Part 5 – Quality Assurance, Part 6 – Mechanical Engineering, Part 7 – Process Engineering.

The first part “Design Engineering” includes recent advancements in design processes and adaptive control systems. It presents studies in designing mechatronic systems, spatial elements of wheels, and automated control of gear profiles for hydraulic machines. This part includes studies in design measures to ensure the reliability of bearings, pneumatic cylinders, and various technological equipment. Ways to design self-adjusting systems are also presented in this part.

The second part “Manufacturing Technology” includes ways to implement intelligent solutions for integrated management systems. It presents recent developments in the manufacturing of parts using additive manufacturing technologies. This part contains studies on controlling system parameters, ensuring the accuracy of manufactured products, and increasing the efficiency of adaptive groups in layered manufacturing. Finally, optimal conditions for the deformation of the stamping-drawing process from aviation materials, ways to increase the efficiency of dynamic characteristics, and control of thermomechanical conditions for heterogeneous materials at finishing operations are also presented in this part.

The third part “Machining Processes” consists of numerical simulations of the diamond grinding process, vibration processing of parts, and evaluation of operating conditions upon intermittent grinding. Studies on deformation mechanics during broaching of cast iron workpieces and finite element analysis of the cutting forces in face milling of gray cast iron are also included in this part. Additionally, the third part deals with optimizing the cutting process based on thermophysical characteristics and evaluating the influence of the back rake angle of a threading cutter on the drill-string tool-joint pitch diameter.

The fourth part “Advanced Materials” is devoted to applying new complex treatments to ensure the functional properties of the surface layers of machine parts and the method for evaluating the resource of diffusion coatings under fatigue conditions. Investigation of the corrosion resistance of permeable porous materials with protective coatings and the effect of ligatures on microstructure and mechanical properties of automotive materials are presented in this part. The fourth part also aims to synthesize copper nanoparticles on graphite using transient glow-to-arc discharge plasma and evaluate surface texture in laser selective melted alloy parts processed by shot peening. It finally includes a comprehensive analysis of the fatigue strength of steel samples after friction treatment.

The fifth part “Quality Assurance” presents a general approach for tolerance control in quality assessment for technology quality analysis, a universal quality control system for industrial enterprises, and modernization of the internal audit process using a risk-based approach. The advanced technology of economic efficiency evaluation and the taxonomy approach for engineering education outcomes assessment are also included in this part. The fifth part also describes problems in the modernization of packaging technologies and improving operational parameters for high-precision tribosystems.

The sixth part “Mechanical Engineering” is based on recent developments in vibration damping of lifting mechanisms, the dynamic behavior of a vibratory plate compactor on the elastic–viscous–plastic surface, and stabilization of natural frequency oscillation equipment. It includes theoretical studies in particle dynamics under oscillating and rotary movements and Lyapunov function-based approach to estimate attractors for dynamic systems. Moreover, the sixth part is based on recent advancements in wave propagation, tube buckling analysis, strength evaluation for cast parts, and contact between elements of hydrovolumetric transmissions.

The seventh part “Process Engineering” presents research studies on temperature distribution in vehicle disk brakes, the efficiency of convective heat exchange in friction elements, and fluid cooling of friction couples. Research work on the changes in the output parameters of hydraulic machines and numerical modeling of point defect formation at nuclear power plants are also presented in this part. The seventh part also includes failure analysis of refractories in rotary kilns and ways to improve the performance of vortex superchargers.

The editors appreciate the outstanding contribution of all the authors. We are deeply convinced that the research papers presented in the book will be helpful to scientists, industrial engineers, and highly qualified practitioners worldwide.

We appreciate a reliable partnership with Springer Nature, iThenticate, and EasyChair for their support during the preparation of InterPartner-2022.

Thank you very much to InterPartner Team. Their involvement, devotion, and hardwork were crucial to the success of the conference.

InterPartner’s motto is “Science unites people together”.

September 2022

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Mechatronic Transducer for Two-Level Adaptive Control of CNC Machines

Anatoly Gushchin[1], Vasily Larshin[1](✉), Oleksandr Lysyi[2], and Victor Marchuk[3]

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Abstract. A new direction has been formulated in developing hierarchical adaptive control of machine tools based on using a mechatronic module (MM) mounted in the electro-spindle of a modern CNC metal cutting machine. The MM operation principle is due to its chosen method: either a device for generating a control servo signal for the machine CNC system or a mechatronic power converter. In the first case (generating a control servo signal), the MM generates an unbalance servo signal which represents the required (according to the machining technology of the part) dependence of the force-torque parameters on the path traveled (along the CNC program trajectory) with adjusting the feed from the CNC machine system. In the second case (power converter), the MM works independently of the machine CNC system, maintaining communication with it. An example of a one-dimensional servo automatic control system is considered for the operations of drilling holes and forming grooves when diamond grinding inscriptions and patterns on the surface of parts, including parts made of superhard materials. During multidimensional machining of complex-profile surfaces (turbine blades, impellers, implants, etc.), the MM is embedded in CNC machines' corresponding coordinate electric drives. In addition to adaptive control of the axial force and cutting torque, the developed MM design can take into account other signals (other than axial force and torque) generated by the monitoring system of the CNC machine for intelligent control.

Keywords: Mechatronic module · Equilibrium state · Hierarchical control · Compensating link · Tracking system · Cutting torque · Superhard material · Artificial intelligence · Product innovation

1 Introduction

Scientists of the past and present century have done a lot of work on introducing adaptive control systems for the mechanical machining of parts made of materials with high strength characteristics and special anisotropic properties into production. However, the results obtained in practice, in terms of the effectiveness of such systems (excess of

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benefits over costs), turned out to be inadequate to the expected results. It is caused by the belated detection of an imbalance of forces arising in the cutting zone.

The paper will show how to immediately direct the identified imbalance to eliminate this imbalance. To do this, you must first create a balanced system of cutting forces (and/or torques) in a closed elastic system of the machine. In case of violation of the force balance, it is necessary to restore it automatically (by returning to the force balance) by changing the size of a special "compensating link" (in the closed dimensional chain). In machine assembly technology, this method has been called the "regulation one". However, until now, it has not been used for adaptive control to stabilize the size of the so-called "closing link". In other words, by feeding excessive force-moment effects into the machining zone, it is necessary not only to fix them but also to simultaneously use the resulting reactions to restore the equilibrium state of the closed elastic system of the machine. In this regard, the following three theses have been formulated and implemented.

1. A mechanical system that implements any tool movements (affecting the resulting size) in the cutting zone from the machine side must allow reciprocal (i.e., directed in the opposite direction) movements of the tool, the power source of which is excess energy $\Delta E = T \cdot \Delta\varphi$, where T is the torque (N·m); $\Delta\varphi$ is the increment of the angle of rotation of the tool (rad). This excess energy can be compensated by changing the linear size Δz of the "compensating link". For example, when drilling $\Delta E = F_{thrust} \cdot \Delta z$, where F_{thrust} is the increment of the axial force, N. Therefore, to compensate for the emerging imbalance, the "compensating link" of a closed dimensional chain must change its size by the following amount proportional to the increment of the angle of rotation of the axial tool (or spindle) $\Delta z = \frac{T}{F_{thrust}} \Delta\varphi$. Thus, a mechanism is needed to convert the excess energy ΔE into the increment of the tool rotation angle $\Delta\varphi$. For example, cam mechanism, screw, or friction ones are suitable for this.
2. The response movements of the tool (because of their smallness) can be "absorbed" by the elastic displacements of the tool cutting edge from the workpiece. Hence, for the mechatronic module (hereinafter MM), the operation of the criterion of constancy of elastic displacements that absorb the increment Δz can be used. A change in the size of the "compensating link" of the dimensional chain by an amount Δz occurs at a constant cutting force (and/or cutting torque).
3. Adaptive control systems on CNC machines must have "reasonable behavior", which is inherent in living organisms. To do this, their design should include "sensory organs" and elements of artificial intelligence. In this case, the property of a living organism is used to get rid of irritation (and to protect itself), preventing its development over time. In other words, the MM either immediately generates a control signal for the machine's CNC system (monitoring mode) or autonomously (i.e., by its own means) eliminates the irritation (and protects itself) that has arisen (adaptive control mode). All three theses can be implemented using the MM in a tracking servo drive for the feeding tool on a CNC machine.

That is why the purpose of the paper is to develop a mechatronic transducer based on the MM mentioned that generates a control signal for interaction with a higher-level system, which is the CNC system of a mechatronic CNC machine.

2 Literature Review

Mechatronics is a new scientific discipline that has taken the high position that previously belonged to cybernetics over the past few decades. Today, this synergetics integrates different disciplines: electronics, information technology, and mechanics [1]. Key elements of mechatronics – physical system modeling, signals and systems, computers and logic systems, software and data acquisition, sensors, and actuators – are naturally accompanied by automatic control. That is why system interfacing, instrumentation, and control systems themselves are the subject of studies [2].

Modern control theory's well-known control principles (by deviation and disturbance) are accompanied by a new direction: distributed and hierarchical control systems. According to hierarchical control, there are four system levels (from bottom to top): a component level, and information preprocessor level, an intellectual preprocessor level, and a top-level [3, 4]. There are three feedback kinds from the lower levels to the upper ones: (1) low-level sensory feedback, (2) intermediate-level feedback, and (3) top-level feedback [3]. So we have the so-called distribution of control available geographically and functionally in a complex control servo system. The computers in the hierarchical system communicate using a suitable communication network. Information transfer in both directions (up and down) should be possible for best performance and flexibility. However, there is no concrete example of the implementation of such hierarchical control.

The two-level industrial servo system has the same shortage [5]. For modeling a multi-jointed robot, this system contains a mechanism part, an actuator at the lower level, and an upper-level controller at the upper level. The servo system of each axis is constructed by the motor part, power amplifier part, current control part, velocity control part, position control part, and sensor (position detector, velocity detector, current detector). But nothing is said about the mechatronic servo actuator, which generates a position signal.

Essential control theory, as well as transfer functions and state space approaches in this theory, are the base for developing the related systems mentioned above [6]. But the professional society literature ignores electromechanical devices other than, e.g., generators and motors. Because: (1) their designs are diverse and may have strange-looking structures, (2) their engineering is based largely on judgment, inventiveness, and experimentation as well as on mathematical analysis [7]. At the same time, in the real world, mechanical engineering and electrical engineering are inextricably entwined. Every electrical device is a mechanical device designed for its electrical properties and manufactured in a factory of mechanical machines. Many mechanical devices are partly electrical, and most are made by machines that are electrically powered and electrically controlled [7]. Moreover, machine tools are mechatronic systems themselves [8]. Hence, they are open to the inclusion of mechatronic mechanisms in them, but there are no hints of it in the literature.

Permanent magnetic force is equivalent to buoyant force and is used to reduce bearing friction in watt-hour meters and other instruments. Besides, electro-magnetic force levitation (MAGLEV) is a technique to reduce friction in experimental high-speed trains [7]. But there is no information on the details of the MAGLEV device. There is no information on the idea that many electro-magnetic transducers generate an intermediate parameter, such as mechanical displacement [7]. This information is exactly what this paper is about. But there is only an idea on a mechatronic transducer.

There is a design of a mechatronic electro-spindle containing a mechatronic actuator [9, 10]. But the hierarchy of the mechatronic servo system containing the machine CNC at the upper control level is not disclosed. The same applies to the so-called intelligent automated drilling in laminate composites and hybrid materials [11].

At the end of the review, it is necessary to mention works on a study of the quality of machined parts made of carbon fiber [12], CFRP [13], and composites [14, 15], as well as works on the physics of electromagnetism [16, 17]. The first case (quality of machined parts) determines the relevance of mechatronic technological systems, including the mechatronic servo system. The second one (physics of electromagnetism) allows the development of such systems.

Monitoring CNC machining applications allows the production to be analysed and improved, improving part quality [18, 19]. Online process monitoring can allow the machine to become more intelligent and adapt to its conditions internally. Machine learning and adaptive machining could further help improve manufacturing efficiency. Therefore there is a need for a low-cost, flexible sensor system that is easy to apply to currently existing CNC technologies [20].

3 Research Methodology

3.1 Conclusions from the Review

Literature analysis allows the formulation of two possible modes of MM operation as part of hierarchical mechatronic systems: (1) the use of MM as a transducer (source of information); (2) the use of MM as a power mechanism (convertor) for adaptive control. In the first case, MM detects a deviation, for example, based on the current position of the working body (or tool). The machine's CNC system eliminates this deviation detected by the appropriate feed selection (deviation control). In the second case, the MM is used directly for adaptive control by disturbance.

Literary analysis has shown that when developing control systems, such features of the control object as anisotropy and high hardness of materials to be machined are not taken into account. In this regard, the proposed methodology contains the following four principles (see also three theses in the paper's introduction).

1. "Intervention" in the cutting process should begin at the stage of its preparation (pre-production stage). In this case, it will be controlled based on reference and empirical data.
2. Possible deviations during the cutting process, e.g., the cutting torque increment, must be used either as a deviation signal for a higher level system, for example, CNC level. This signal is used for direct control "by disturbance".

3. The force-torque parameters of the interaction of a cutting tool with a workpiece – parameters that are formed in the cutting zone – must be included in the servo system as an independent cutting parameter set by the MM, just as speed or displacement (path) are independent parameters in the conventional CNC machine system.
4. Control over the progress of the cutting process must be carried out according to the totality of many parameters (taking into account their weighting significance), including indirect signs that precede the occurrence of undesirable phenomena in the cutting zone (increasing noise, vibration, temperature).

All four above principles have been verified by many years of practice in introducing fundamentally new technologies for cutting hard-to-machine materials on a CNC machine into industrial production (Fig. 1).

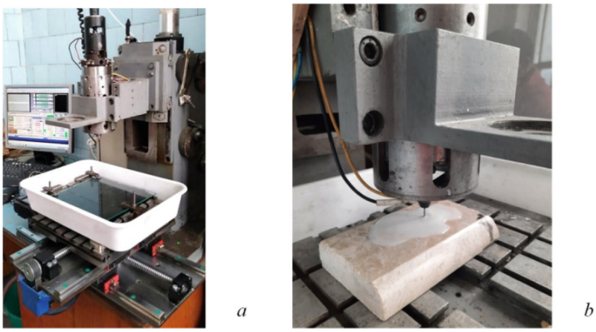


Fig. 1. Mechatronic technological system (MTS) based on a 3D CNC machine when processing glass (*a*) and stone (*b*).

3.2 Multi-level Control

Two-level control at the pre-production and production stages allows the creation of a single integrated design and production automation system. In such a system, optimization plays the part of both a design method – at the upper level of hierarchical management – and a control method – at the lower level.

Let us explain the above in greater detail. In the language of control system theory, on the upper control level, a relative decision is made which is not based on some control (reference) points depending on the machine shop's actual conditions. Consequently, it will be some formal decision. On the contrary, a robust control system on the lower control level considers the shop's existing conditions. Sometimes, it will be with the help of the so-called RDT and E laboratory (an intermediary between the upper and lower levels of control) (Fig. 2).

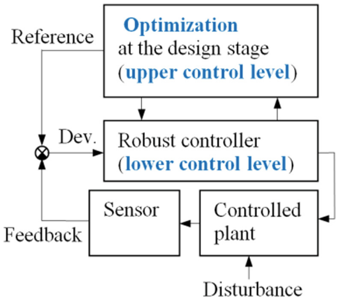


Fig. 2. General scheme of the two-level hierarchical automatic control system.

3.3 Methodology for Programming Systems of the Upper and Lower Levels

MM is intended mainly for CNC machines to ensure maximum productivity with guaranteed quality due to the automatic control servo system operation. This servo system is got (in each tool axial movement coordinate) the required value of the cutting torque, e.g. $T_i(z_i)$, found at the pre-production stage. For example, for the one-dimensional case (hole drilling), this servo system, due to the MM, implements the functional dependence $T_i(z_i)$ in the tracking servo mode. With an increase in the number of controlled coordinates, e.g., up to three, the tracking servo control is provided for each of these coordinates by the corresponding electric drives for each point of the tool trajectory in space. In other words, in the servo mode, three functional dependencies are simultaneously performed: $T_i(x_i)$, $T_j(y_j)$ and $T_k(z_k)$, where x_i, y_j, z_k are the coordinate values at the points with ordinal numbers i, j and k.

For example, the coordinate z_k (instantaneous scalar value of the vector z at the point k) is set by the machine CNC system (the upper control level system). The corresponding torque values are set by the controlling computer that sets the torque parameters of the cutting operation (lower level control system), i.e., robust servo system of automatic direct control "by disturbance". The controlling computer has a vector $\boldsymbol{T}(z)$ generator. Thus, when compiling a program for the tool spatial movement, predetermined force-torque characteristics of the machining process are introduced simultaneously into the upper and lower control systems, i.e., both the machine CNC and the tracking servo system, respectively. The tracking servo system fulfills this instruction by maintaining a machining process's force and torque characteristics at a given level (the machine CNC system sets the level).

4 Results and Discussion

The MM includes a base 1, on which mounting elements 2 are installed, carrying a ferromagnetic housing 3 of a linear DC actuator (Fig. 3). Housing 3 also acts as an external magnetic circuit of the same actuator. In housing 3, coaxially to it, a cylindrical internal magnetic core 4 is rigidly fixed, having a field winding divided into two Sects. 5 and 6, creating a total magnetic flux (not shown) in the above-mentioned magnetic circuits 3 and 4. The magnetic flux has the desired both size and direction. In the working gap between the magnetic circuits 3 and 4, there is a hollow cylindrical non-ferromagnetic armature 7, which has an armature winding 8 on its left side. A ring-shaped (annular) permanent magnet 9 is fixed on the right end of armature 7, which moves together with armature 7 as a single solid body.

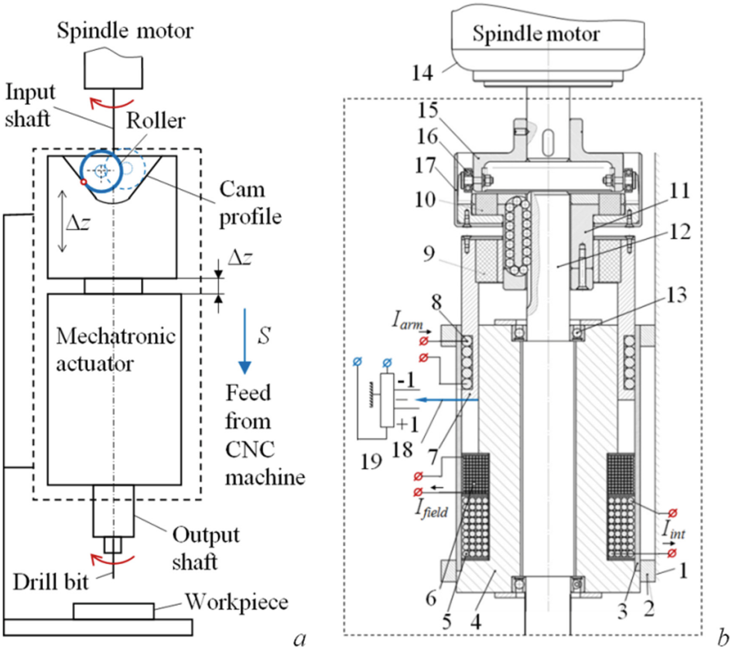


Fig. 3. General scheme of a mechatronic module (*a*) and the same in details (*b*).

Cylindrical magnets 10 (at least two pieces) are installed on the peripheral part of the end face of the flange-ball-spline assembly 11, opposite the magnet 9, so that only repulsive forces arise between the ring-shaped magnet 9 and cylindrical magnets 10. The same name poles of magnets 9 and 10 should be located opposite each other. The overall dimensions and the number of cylindrical magnets 10 are selected depending on the overall design features of the MM.

The ball spline assembly 11 is mounted on shaft 12 (with ball spline grooves). It can transmit torque from the right half coupling with cutouts (cam internal surface) and reciprocate movements along the longitudinal axis of shaft 12.

The shaft 12 is rigidly fixed in the magnetic circuit 4 using the lower (not indicated in Fig. 3) and the upper 13 ball bearings, resulting in which it can rotate and transmit torque.

The torque to the shaft 12 is transmitted from the motor 14 utilizing a driving coupling 15, on the outer cylindrical surface of which two ball bearings 16 are symmetrically fixed so that their axes are perpendicular to the longitudinal axis of the driving coupling 15, and the outer rings have the possibility of rotation.

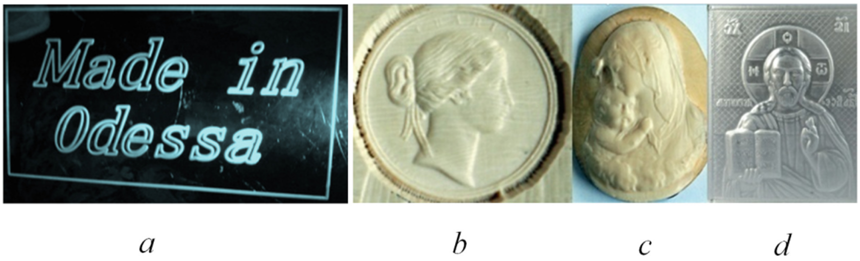
Ball bearings 16 enter slots (the working surface of the inner cam) made on the lateral cylindrical surface of the driven coupling 17. These slots have the shape of a triangle with a semicircular vertex. The coupling half 17, in turn, is fixed to the ball slot connection 11.

To fix the linear movements of the armature 7, a movable element 18 of the linear displacement sensor 19 is fixed on armature 7, which is informatively connected to the controlling computer of the lower-level tracking servo system (not shown in Fig. 3). The armature winding 8 is powered from a DC source through a unit controlled by the same computer. Section 6 of the field winding is also controlled by this computer.

Section 5 of the field winding is an element of the lower level of control, which can make adjustments to the program of actions of the CNC machine based on information coming from the zone of force interaction of the working tool of the same machine with the external environment (by analogy with the peripheral nervous system of man). To perform such functions, Sect. 5 of the field winding receives signals generated by the control-and-measuring equipment from the zone of force interaction. These signals characterize the adequacy of the ongoing machining process according to the programmed power parameter (axis force or torque).

To fix any deviations in the machining process from the norm (the upper control level sets the norm), the MM as a whole is equipped with various kinds of control-and-measuring equipment and the necessary sensors: video surveillance cameras, microphones, temperature sensors, strain gauges, vibration acceleration sensors, etc. These sensors should be regulated for each specific machine operating in certain conditions.

Special control programs have been developed for an experimental CNC machine containing MM (Fig. 1) to realize the methodology described above. The programs take into account the specific features of the material to be machined: strength (for glass), thermo-physical properties (for CFRP, syntegran), and others. For example, experimental studies have been carried out on contour 2D grinding of inscriptions and patterns with a grinding depth of 0.5 mm on glass with a thickness of 3 mm with diamond cylindrical tools with a diameter of 1.1– 4.0 mm. The power parameters of the process – axial force F and torque T– for contour grinding were selected by adjusting the current in Sect. 6 of the field winding (I_{field} in Fig. 3, *b*) and the armature winding 8 (I_{arm} in Fig. 3, *b*) in the following ranges: $0.8 \leq F \leq 1.2$ N and $0.04 \leq T \leq 0.06$ N·m. As a result, exclusive products were obtained (Fig. 4) from ordinary technical glass (*a*), from a mammoth tusk (*b*, *c*), and special optical glass (*d*).



a *b* *c* *d*

Fig. 4. Exclusive products made of hard-to-machine materials.

5 Conclusions

A new scientific and technical direction has been formulated in developing hierarchical adaptive control of machine tools based on the use of a mechatronic module (MM) mounted, as an example, directly on the carriage of vertical feeds of a CNC metal cutting machine.

The principle of operation of a mechatronic servo system based on the MM is determined by the chosen method of its implementation: either by the method of generating a control servo signal for the machine CNC system (transducer and monitoring function) or by the method of automatic control with the power mechatronic converter. In the first case (formation of the control signal), the MM generates a control signal proportional to the amount of feed the machine CNC system sets according to this signal to ensure the tracking servo mode of forming the cutting torque. This case is considered in the paper. In the second case (power converter), the MM has the necessary autonomy and maneuverability for stabilizing the cutting torque independently of the CNC machine system but when working in conjunction with it.

The paper considers an example of a one-dimensional servo automatic control system on the example of drilling and diamond grooving when grinding inscriptions and patterns on the surface of superhard and other hard-to-machine materials. In multidimensional machining of complex-shaped surfaces (turbine blades, impellers, implants, etc.), the MM is built into the corresponding coordinate electric drives of CNC machines and works according to the methods described above.

In addition to adaptive control for cutting axial torque, the developed MM design can take into account other (except for force and torque) signals generated by modern monitoring systems on CNC machines: acoustic emission (in the frequency range of 0.2–2.0 MHz, sound signal (0.1–20.0 kHz), Barkhausen noise (0.06–1.0 MHz), temperature, electromagnetic field, radioactive radiation, etc.

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Reverse Engineering and Design Process as Set of Procedures

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Abstract. Equipment that has failed can be repaired, redesigned, or an alternative method of use with limited functionality can be found. Reverse engineering of equipment includes all or part of the stages of the design process. The design process was explored in more detail than the relatively new direction of reverse engineering. Using the experience gained in structuring and automating the design process, it is advisable to improve the reverse engineering methodology. It was proposed to present the design process and reverse engineering procedures. The designing and reverse engineering processes were identified. The procedures were divided into heuristic, design techniques calculation, and metrological procedures. The reverse engineering model shows the place and interaction of these groups. The procedures are considered a symbolic designation, allowing us to present the reverse engineering process as a symbolic sequence.

Keywords: Design process · Reverse engineering · Morphological map · Sustainable manufacturing

1 Introduction

Most researchers narrowly understand reverse engineering: "reconstruction of CAD models from measured data" [1]. A similar idea is at the heart of reverse engineering of software, based on the analysis of dirty source code and finding the initial specification [2], discovering initial models from the legacy artifacts composing a given system, in other words, "discover initial models from the legacy artifacts composing a given system" [3]. With this approach, reverse engineering of equipment involves the following steps: determination of product parameters based on measurements of a real object; the use of special equipment for scanning surfaces; the use of software for the building of 3D surfaces. Researchers are looking for ways to describe the surface of a part as accurately as possible, such as using "tensor-product surfaces" [4] or making the surface "topologically consistent, and it is flexibly editable" [5].

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