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TECHNOLOGY FOR COMPLEX PARTS MACHINING IN MULTIPRODUCT MANUFACTURING

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Abstract
At present, the speed of production and its complexity increases with each passing year due to the shorter product life cycle and competition in the global market. This trend is also observed in the machine-building industry, therefore, in order to ensure the competitiveness of enterprises and reduce the cost of production, it is necessary to intensify production. This is especially true in the machining of complex parts that require a great number of setups, and technological equipment. The problem-oriented analysis of complex parts was carried out, the parts classification was structured and developed according to the design and technological features. This made it possible to offer advanced manufacturing processes for complex parts like levers, forks, and connecting rods. The flexible fixtures for specified complex parts were developed. The effectiveness of the proposed manufacturing processes, as compared with the typical ones, provides significant improvement in the production.

Keywords
classification, lever, fork, connecting rod, manufacturing process, fixture, labor content, setup time.

Introduction

In the modern world, it is important for machine-building enterprises to be competitive in world markets for products. This requires constant modernization of production, the use of advanced metalworking equipment, cutting tools and fixtures. Modern machining centers provide a wide technological capability, which contributes to the improvement and development of new approaches to the design of manufacturing processes, including multiaxis machining in one setup. The purpose of the paper is to intensify the manufacturing processes of the complex parts machining due to the use of flexible fixtures, allowing to execute the maximum number of manufacturing steps in one setup.

Literature review

The analysis of the resent research has shown that the design process of the fixture is a labor-intensive and comprehensive process that needs to take into account many parameters. Therefore, in fixture design, as a rule, the technological system "machine tool – fixture – cutting tool – workpiece" is considered as a whole, as well as other production factors are taken into account.

A row of the recent results highlights the research novelty and practical significance of the proposed research. Particularly, in the paper [1], the APM Graph module is proposed to use for the spatial parametric position of the functional elements and the local coordinate system for the machine spindle case study.

The paper [2] proves the fact that the modular fixtures are the most used ones during the machining. Moreover, it is stated that the precision of the machining process is a result of the fixture's stiffness, which depends on the stiffness of its functional elements.

As a result of the research [3], the methodology for numerical evaluation of the technological process parameters is proposed based on the experimental verification of production technology.

The paper [4] is aimed at the identification of the importance of implementing a knowledge sharing process by means of integrating key component suppliers. As a result, the research underlines the significance of knowledge management as a core value for just-in-time production.

The paper [5] deals with the interaction between functional elements of the system "fixture – workpiece". As a result, the methodology for the optimization of clamping elements is proposed.

As a result of the research [6], the way for reduction of cycle time is proposed by applying the lean tools and managerial principles. Additionally, the corresponding software is used for the numerical simulation of the stream maps, as well as for the evaluation of changes in the cycle and waiting times, and machine utilization. In the paper [7], lean approaches and corresponding practical techniques in an industrial environment are applied for the automotive industry.

The research [8] deals with the requirements for the software applications based on computer-aided process planning (CAPP) within the Industry 4.0 strategy. As a result of the analysis of the global industrial market, a brand-new information system are designed and successfully implemented into industrial companies.

A summary of the recent development in the field of technical diagnostics is presented in the paper [9]. As a result, basic approaches to the implementation of measurement tools are developed for the case of machine tool and industrial robot diagnostics.

In the paper [10], the importance of the workpiece clamping and corresponding systems for realizing flexible workpiece exchange is highlighted. As a result, ways for implementing interchangeable designs of CNC machine tools with confined workspace are developed.

The paper [11] describes the experimental research using convolutional neural networks for the identification of assembly parts and features. The proposed approach is realized by the augmented reality software.

The research work [12] is aimed at the development of the simulation software for the improvement of the production process. As a result, a simulation model of the manufacturing process is proposed, and the corresponding approach for ensuring the material efficiency and production capacity of the entire production system is devised.

The paper [13] deals with the implementation of flexible production systems. As a result of the research, the variety of modular flexible production systems is analyzed, and the advantages of flexible solutions are described.

In the research [14], up-to-date technologies of clamping collets manufacturing are proposed based on the theoretical and experimental investigations. As a result, the corresponding approach for manufacturing non-adjustable collets is developed.

The prevention methods of undesirable deviations during the machining process are presented and precisely analyzed within the research [15] on the example of using the engineering automation as a technological solution for the milling of spatially complicated parts.

The paper [16] is aimed at the intensification of complexity and functionality of the manufacturing environments within huge competitiveness in the global market. The main results are obtained by means of the cloud manufacturing process and big data in networked manufacturing systems.

The significance of different approaches for improvement of production processes, their maintenance, and practical applications are discussed in the paper [17]. As a result, the production process is realized under the "Strategies of Efficient Action" using the "Practices of Efficient Action" supporting methods. The proposed approach is highly useful within applying the power of TQM, Six Sigma, and Lean Manufacturing strategies.

The research paper [18] proves the effectiveness of conventional machine tools with numerically controlled machinery (CNC), which require the simultaneous conducting of actions related to organization and control of production, management of human resources, and tool economy.

The paper [19] determines the terminology and presents the advantages and disadvantages of numerical compensation of machine tools and measuring machines errors. Based on the principle of reduction of the proposed models and volumetric error distribution, an array of reduced models for three-axis machine tools is obtained.

In the research [20], the up-to-date method of spatial parts machining is proposed for practical application. The obtained results ensure the fall of friction assembly normal operation and reduce the possibility of microfractures formation. Additionally, based on the experimental research [21], it has been determined that the production process quality during machining meets the requirements.

In the paper [22], a new method for forecasting the development of industrial enterprises is developed, and the corresponding computational experiment is carried out.

The advantages and disadvantages of quality management systems are discussed in the paper [23] on the example of machine-building enterprises. As a result, a methodology of applying the quality management system is proposed.

The research [24] deals with the increase of production productivity using industrial engineering methods. An approach for the application of lean methods in the production process is proposed, and the problem of balancing the production line is partially solved.

The paper [25] is aimed at the design of flexible fixtures, which provide a sufficient tool availability and allows multiaxis machining of fork-type parts during a single setup. The ways for intensification of the manufacturing process with a significant reduction of auxiliary and preparatory time are proposed. The carried out numerical experiments confirm the proper accuracy of the proposed design.

The increasing diversity of products is considered in the paper [26], and corresponding ways for overcoming production challenges are proposed based on the product data management (PDM). As a result, enterprise resource planning (ERP) systems and other determining factors are implemented for the successful organizations of the production process.

Wang [27] introduced the fixture layout for the complex parts, based on the concept of optimal planning of the experiment.

Due to the rapid increase in the product range and the reduction of time spent on manufacturing products, while increasing the complexity of finished products (Fig. 1), there is a need to provide sufficient tool availability. Thus, at present, the increase of fixture flexibility and the intensification of manufacturing processes for complex parts machining, considering the expansion of technological capabilities of machine tools capable of multiaxis machining, is an urgent task. This allows the use of reserves to reduce the auxiliary time for part machining, which may be advantageous in terms of cost of production in multi-product manufacturing (small parts batches and the frequent changes of them).

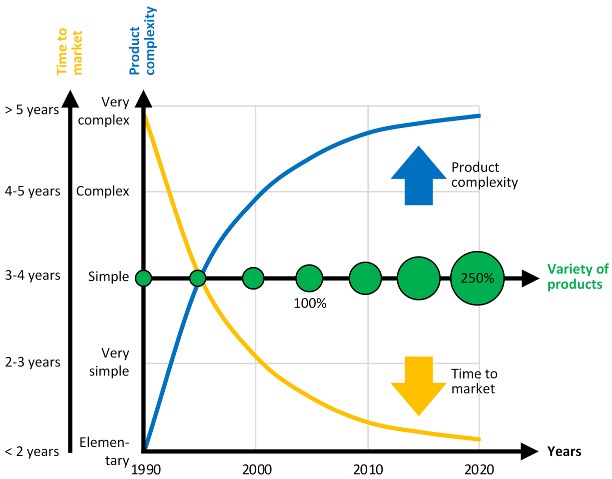

Fig. 1. Challenges in modern manufacturing engineering.

Research methodology

Classification of complex parts

Typical representatives of complex parts in the automotive industry are levers, forks, and connecting rods. They are characterized by the complex spatial arrangement and variety of machined surfaces of parts, which requires the use of complex fixture structures for the implementation of the locating charts with a maximum tool availability.

On the basis of a comprehensive analysis of complex parts, the classifications for the specified types of parts based on design and technological features are proposed. In the developed classifications, all possible configurations of the levers, forks, and connecting rods are taken into account as much as possible. The classification for lever-type parts is presented in [28]. The developed classification of fork-type parts is presented in Fig. 2.

The typical designs of levers, forks, and connecting rods are identified and the main manufacturing steps and machined surfaces are shown in Fig. 3. The nomenclature of these parts is quite large, but the differences in their designs are not significant. For example, one part can differ from the other only in size and a slight variation of the form, which allows us to talk about their design similarity and the possibility of using the flexible fixture, which allows locating and clamping constructively similar parts within a single size group.

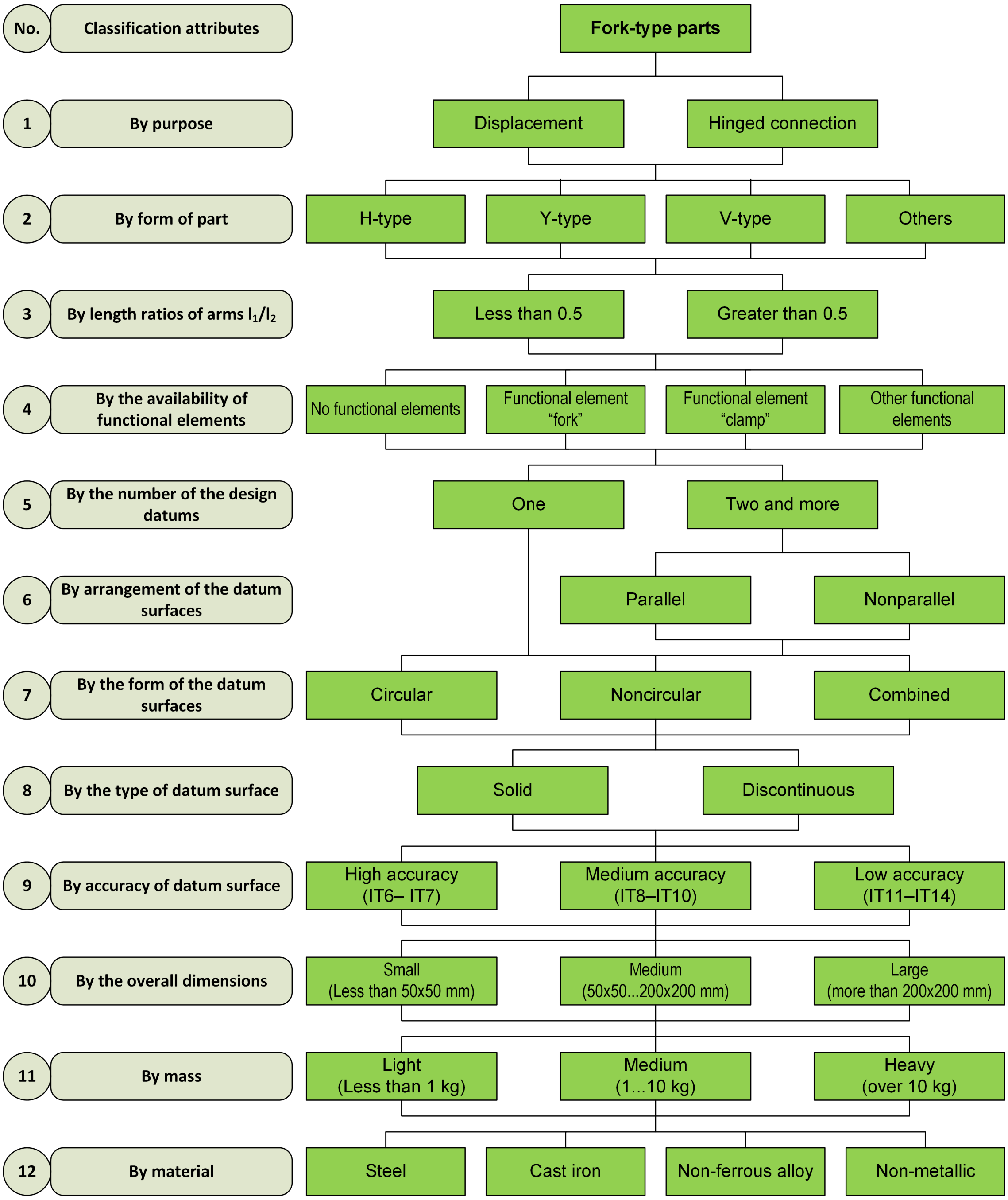

Fig. 2. Design and technological classification of fork-type parts.

The quality of any product depends considerably on the manufacturing technology of its components. Most of the parts of the type of levers, forks, and connecting rods have a complex geometric shape, which causes some difficulties in locating and clamping the workpieces during machining. Traditionally, dedicated or flexible fixtures (usually modular fixtures) are used to install the workpieces, which provide a given accuracy of surface machining but causes to the increase the complexity and cost of manufacturing. Thus, the analysis of a typical manufacturing process for the production of levers, forks, and connecting rods is relevant, with subsequent identification of the possibilities for optimization of manufacturing process taking into account the current trends in manufacturing engineering, as well as the functional and technological capabilities of modern equipment.

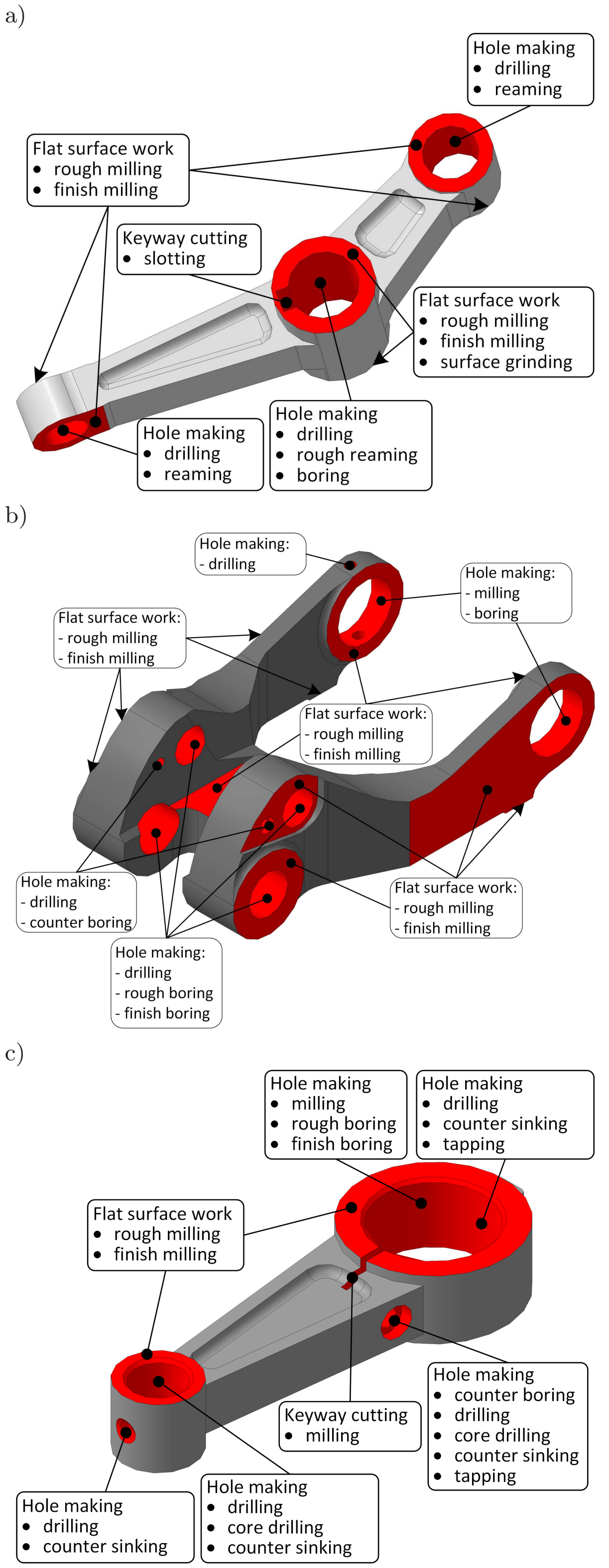

Fig. 3. A typical designs and work surfaces of the complex parts: a) lever-type part, b) fork-type part, c) connecting rod.

The manufacturing processes of complex parts

Existing methods of manufacturing process design, based on the capabilities of the cutting equipment of the previous generation, which does not allow to machine surfaces in different planes by many tools, forced the process engineers to develop manufacturing process on the principle of differentiation of operations. Under conditions of multiproduct manufacturing, it is unacceptable. Taking into account the capabilities of modern metal-cutting equipment, which allows multiaxis machining of parts, it is necessary to change approaches with the aim to intensify manufacturing processes. The main reserve is the development and implementation of flexible fixtures [30], which are characterized by a high level of flexibility and allow the implementation of the fundamentally new locating charts, providing maximum tool availability. New manufacturing processes have been developed for the production of parts such as levers, forks, and connecting rods by combining drilling, milling, and boring operations. This allowed the introduction of multiaxis machining in one setup instead of the 9 setups for the levers (Fig. 4b), 7 setups for the forks (Fig. 5b), and 6 setups for the connecting rods (Fig. 6b).

Fixtures for complex parts machining

Machining efficiency greatly depends on the fixture design which should provide the required machining accuracy, shows sufficient rigidity, and high level of flexibility. In order to implement a workpiece locating charts on CNC multiaxis machining operations, it is introduced flexible fixtures. In general, the structure of the flexible fixture is presented in Fig. 7.

The configurations of flexible fixtures for parts machining such as levers, forks, and connecting rods are proposed [patents of Ukraine 98925, 123854, 123855].

Proposed flexible fixtures are assigned for setup the levers, the forks, and the connecting rods in the certain defined range of parts sizes. It is achieved by control of the adjustment mechanisms, which provide changing the distance between locating and clamping elements (Fig. 8).

Such a solution in conjunction with the power-driven rotary table of the machining center allows carrying out the all drilling, milling, and boring manufacturing operations at one setup, which is realized on the CNC machining center.

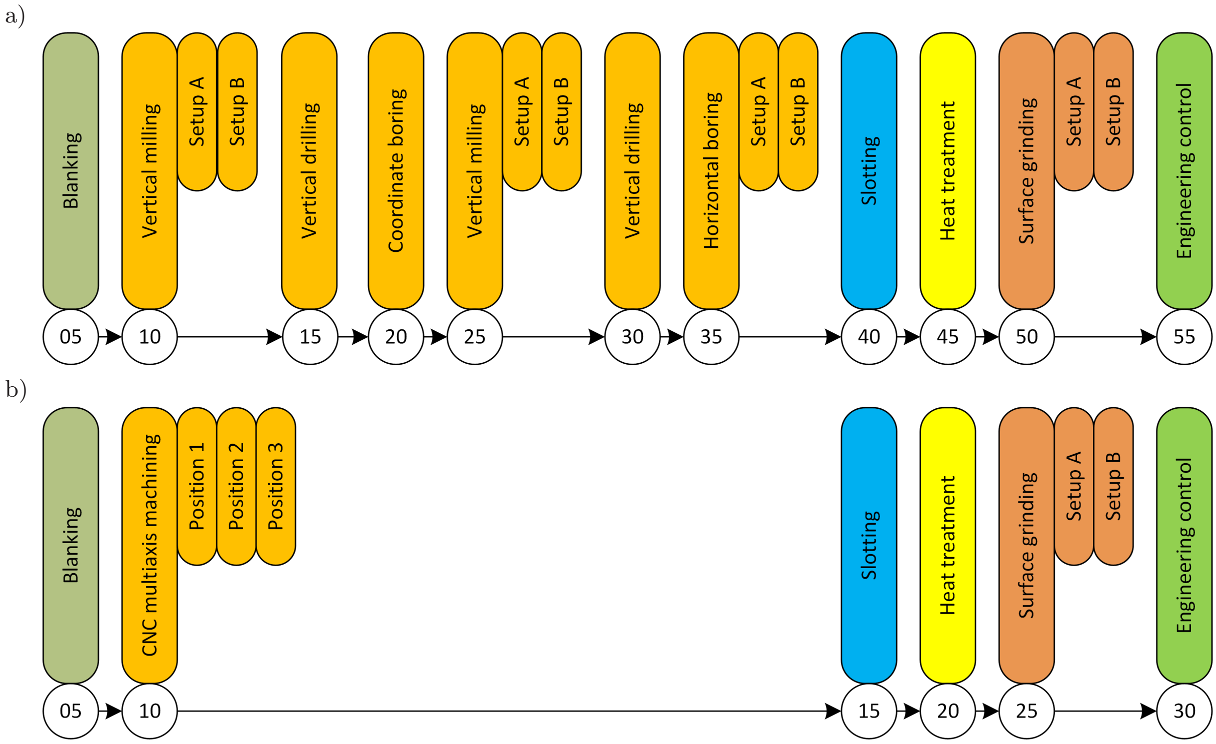

Fig. 4. Comparison of the manufacturing routes for the lever machining:
a) typical manufacturing process, b) proposed manufacturing process.

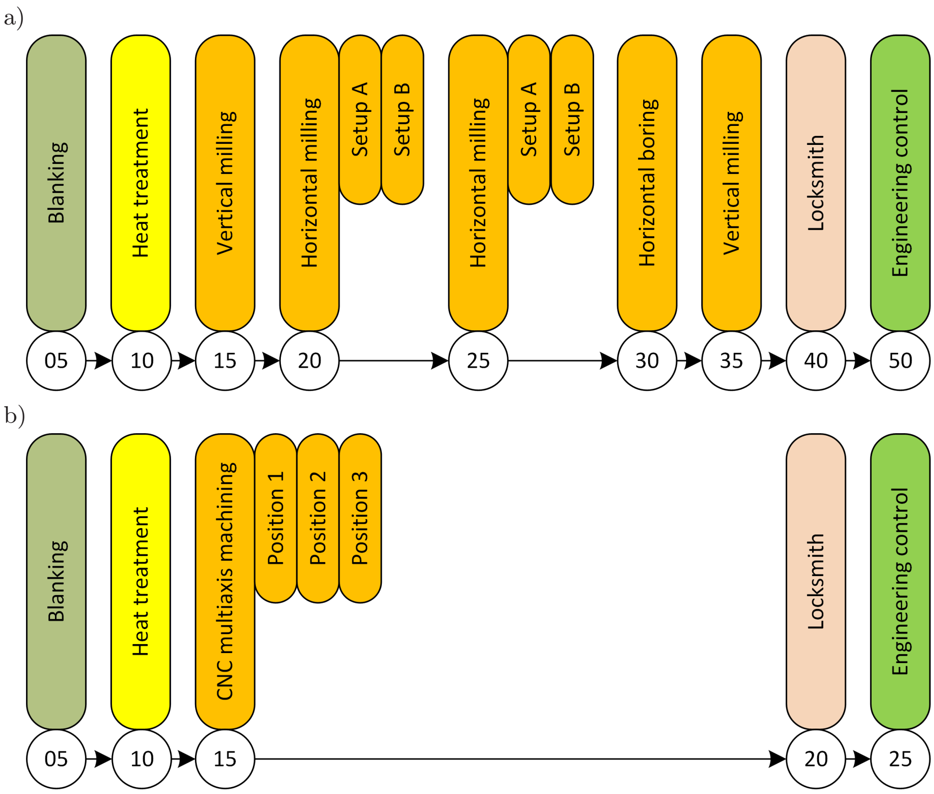

Fig. 5. Comparison of the manufacturing routes for the fork-type part machining:
a) typical manufacturing process, b) proposed manufacturing process.

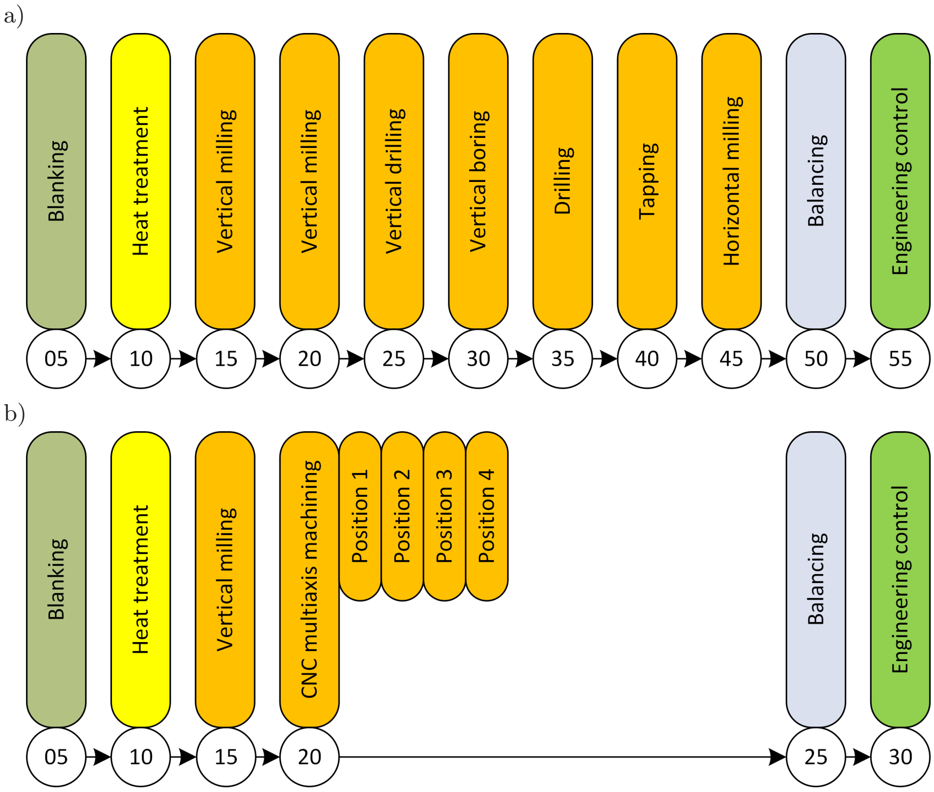

Fig. 6. Comparison of the manufacturing routes for the connecting rod machining: a) typical manufacturing process, b) proposed manufacturing process.

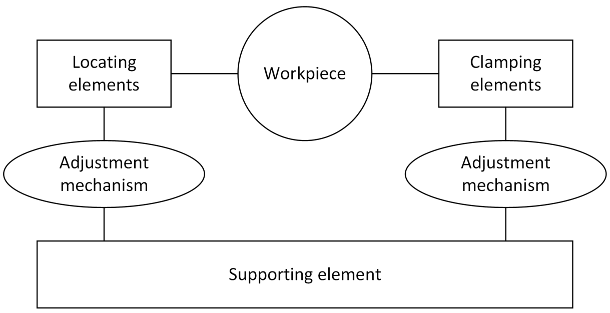

Fig. 7. The principal structure of the flexible fixture.

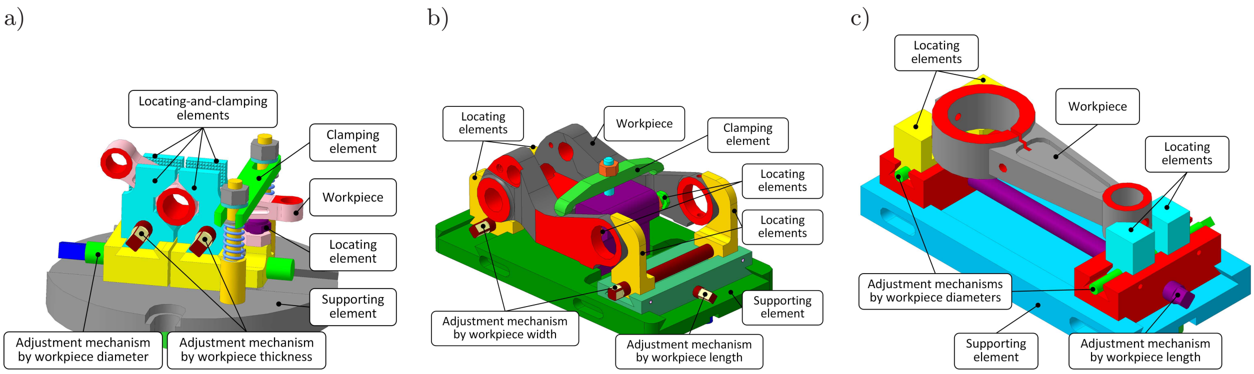

Fig. 8. Flexible fixtures for machining: a) lever-type parts, b) fork-type parts, c) connecting rods.

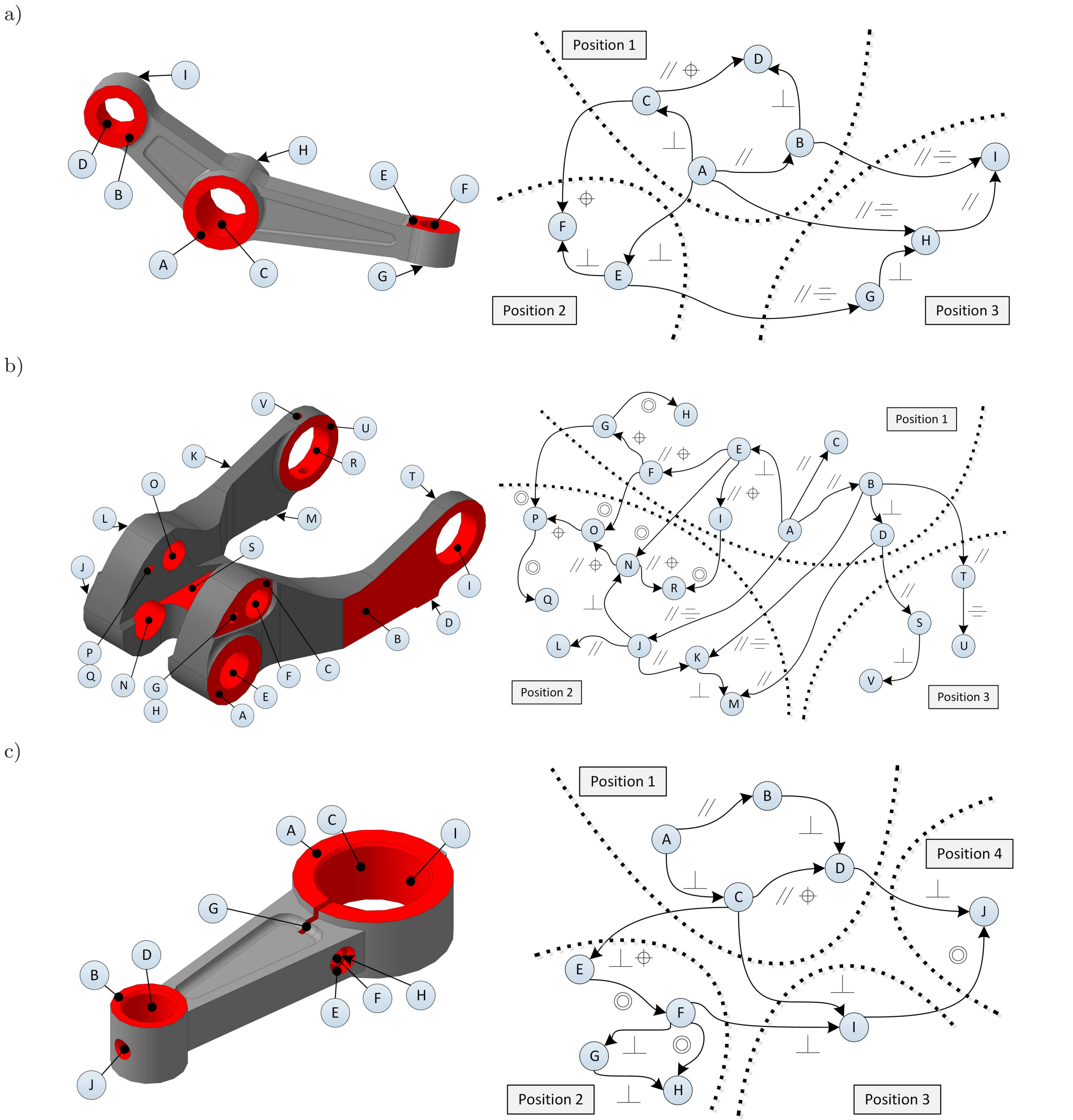

Fig. 9. Graphical relationship between the spatial position of work surfaces for: a) lever-type part, b) fork-type part, c) connecting rod.

In order to optimize the structure of the operation, technological graphs have been developed (Fig. 9). The quality of products greatly depends on the accuracy of sizes, the accuracy of spatial relationships, the accuracy of surface forms, and roughness of the machined surfaces.

The strategy for parts manufacturing is based on the developed technological graphs, which determine the relationship between the work surfaces in different positions. The graphs introduce the order of surfaces machining in achieving the required quality of parts on CNC multiaxis machining operations.

Results and discussion

For the quantitative comparison of the typical and proposed manufacturing processes, the calculation of time standards for drilling, milling, and boring operations is made. Moreover, the comparative calculation was performed on such parameters as the number of fixtures used in those manufacturing operations; steel intensity; the number of setups and resetups; the number of machine tools; the production area. Cutting conditions calculation and timing calculation were performed according to the standard procedures. The production batch was defined as N = 50 pcs. made of 40NiCr6 structural alloy steel. Cutting conditions and cutting tools are the same for both manufacturing processes. Therefore, cutting times in both cases are the same since the identical cutting tools and machining conditions are used. Time for measurements in both manufacturing processes is the same since the number of surfaces for measuring is identical.

The diagrams of time (Fig. 10) provide the following information. Setup time in a typical manufacturing process is characterized by higher labor content because there is the necessity for workpiece setup and resetup in various operations, unlike the only one setup in the proposed manufacturing process. Auxiliary time, additional time, time for personal needs, and preparatory time in typical manufacturing processes are greater than in the proposed ones due to the greater number of operations and working places. Machining time associated with one-piece machining in a typical manufacturing process is approximately twice more than in a progressive one, as it includes all the previous times, except for preparatory time. Machining-calculation time is inversely proportional to the number of parts in the batch, therefore for small batches, it significantly increases in comparison with the machining time.

For all analyzed manufacturing processes of complex parts machining the same tendency is observed, namely reduction of auxiliary time in proposed manufacturing processes in comparison with typical ones.

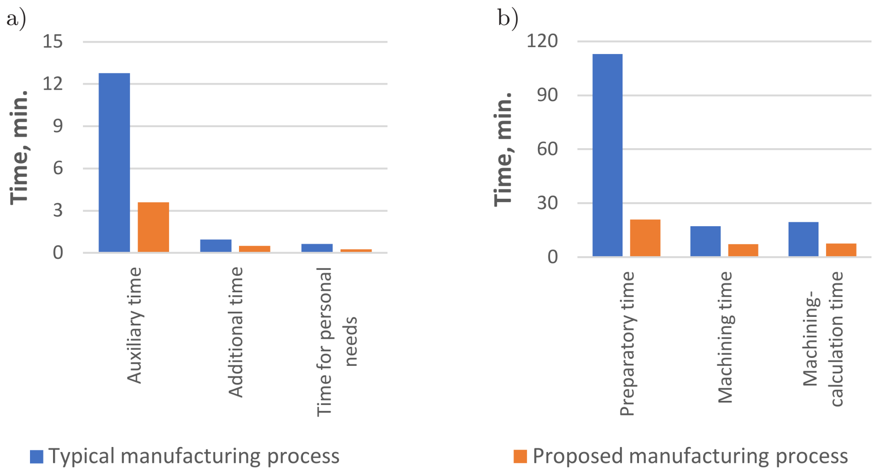

Fig. 10. Comparative analysis of the structures of manufacturing processes by labor-intensiveness for lever-type parts, min: a) for steps that are performed constantly, b) for batch workpieces.

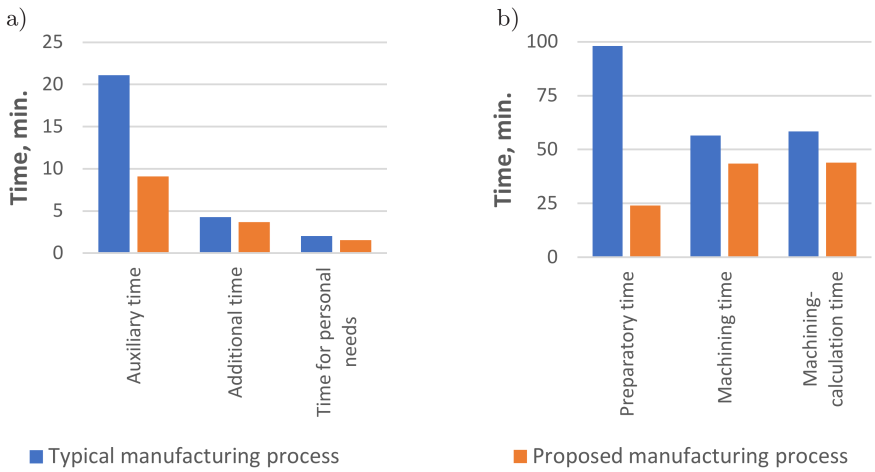

Fig. 11. Comparative analysis of the structures of manufacturing processes by labor-intensiveness for fork-type parts, min: a) for steps that are performed constantly, b) for batch workpieces.

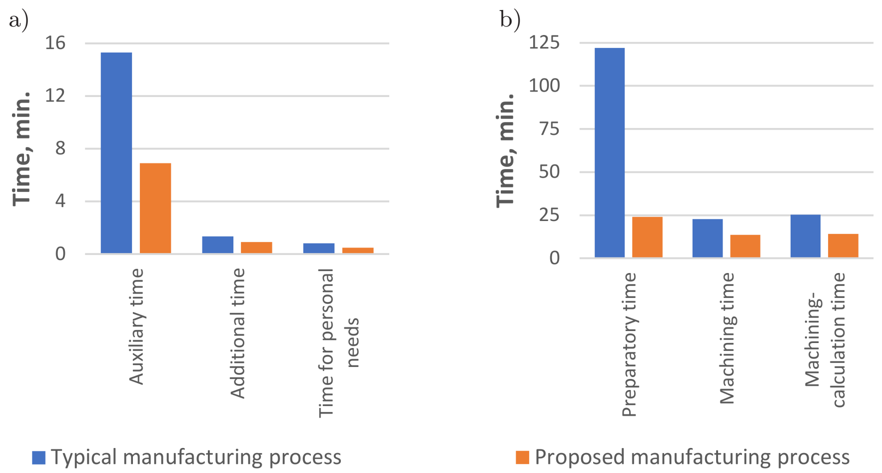

Fig. 12. Comparative analysis of the structures of manufacturing processes by labor-intensiveness for connecting rods, min: a) for steps that are performed constantly, b) for batch workpieces.

Conclusions

1. It is developed the classifications for lever-type, fork-type, and connecting rods-type parts, reflecting the design and technological features, that allow the identification of the groups of parts with similar characteristics. Therefore, they can be grouped and referred to certain dimension types of fixtures, that creates the initial conditions for computer-aided fixture design.
2. Due to the establishment of geometric relationships and the theory of graphs, the optimization of the structure of the operation and the achievement of the accuracy of the spatial relationship of the machined surfaces for parts of the type of levers, forks, and connecting rods in the proposed flexible fixtures are substantiated. The necessity of intensification of complex parts machining by means of calculations and comparison of time norms of the typical and proposed manufacturing processes is proved. It is introduced the manufacturing processes for CNC multiaxis machining centers which allow improving the machining efficiency in 1.3–5 times depending on the batch of parts.
3. Due to the difficulty of complex parts locating in manufacturing operations and their prevalence in the automotive industry which is undergoing a process of constant renewal, the nearest way to improve the manufacturing process efficiency is to develop flexible fixtures that ensure fundamentally new workpiece locating charts, and accuracy requirements, as well as providing maximum tool accessibility, fixture flexibility, and sufficient stiffness.

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