EAI Endorsed Transactions
on Industrial Networks and Intelligent Systems
Research Article EAI.EU

Flexible Fixtures for CNC Machining Centers in Multiproduct Manufacturing

Vitalii Ivanov[1,*] and Jozef Zajac[2]

[1]Sumy State University, 2 Rymskogo-Korsakova St., Sumy, 40007, Ukraine, ivanov@tmvi.sumdu.edu.ua
[2]Technical University of Kosice, 1 Bayerova St., Presov,08001, Slovak Republic, jozef.zajac@tuke.sk

Abstract

In modern manufacturing engineering, a major challenge is the contradiction between the need to reduce the time required to design and manufacture the products and the increasing complexity of product design. Today's market requires more varieties of products, and consequently the equipment and processes should be more flexible. Fixtures play an essential role in production of high-quality and competitive products in multiproduct manufacturing. The paper describes the ways of increasing of machining efficiency of parts. The principally new constructions of functional modules of modular adjustable fixtures for locating and clamping of workpieces are introduced. Use of the proposed fixtures with the possibility of automatized adjustment ensures the spreading of technological capabilities of CNC metal-cutting equipment, decreasing of preparatory time and setup time, and therefore, assists improving of the efficiency of production planning.

Keywords: modular design, CNC equipment, flexibility, experimental research, production planning, machining, efficiency, automotive industry.

Received on 3 December 2017, accepted on 6 December 2017, published on 10 january 2018

doi: 10.4108/10.4108/eai.10-1-2018.153552

1. Introduction

Modern production is characterized by multiproduct manufacturing and instability of the volume of products output. The enterprises of the automobile industry have a large variety of parts, which require the machining for achieving the high accuracy of sizes, forms and relative position, and quality of surfaces in accordance to their intended service. In constructions of automobile units almost all types of parts, existing in design and engineering classifiers of machine-building, are presented, in particular: prismatic parts, covers, cylinder blocks, crankcases, shafts, rods, flanges, discs, bushings, pistons, levers, connecting rods, brackets, etc., which require the accurate location and reliable clamping during the machining for ensuring the parameters, set by product engineer, that allow increasing the efficiency and reliability of the product as a whole.

*Corresponding author. Email: ivanov@tmvi.sumdu.edu.ua

In this regard, much attention is paid to the fixtures, which are used for locating of automobiles parts. It should be noticed that considering the expansion of technological capabilities of modern machine tools, their high cost and the necessity to perform the large number of adjustments while transferring to the machining of parts of other standard size, intensification of manufacturing processes becomes rapidly developed. This provides the increasing of fixture flexibility, decreasing of preparatory time and reset time, and possibilities of multiaxis and multitooling machining of parts per one setup that should be ensured by fixture configuration. All this assists the decreasing of time consumption on the production planning and therefore positively influences on the decreasing of cost of products.

2. Literature Review

The greatest nomenclature of parts in manufacturing engineering is being machined on the drilling-milling-boring

machine tools. It is the highly productive automatized metal-cutting equipment, which allows carrying out the complex machining of the surfaces under condition of unchangeable clamping of the workpiece.

The number of drilling-milling-boring machine tools produced by Japanese machine tool industry is much higher than other groups of machine tools. In 2014 this value reached 60%. Machining centers, which make 95,4% of all machine tools belonging to drilling-milling-boring group, are prevalent. Machine tools' automation is on the very high level; in 2014, this value reached 90,4% [1]. The analysis of German machine tool industry has showed that during 2006–2014 the output of drilling-milling-boring machine tools is prevalent. The part of drilling-milling-boring machine tools is 38% [2–3]. Therefore, the main direction of efficiency increasing of parts machining is the automation of production processes, performed by means of use of CNC machine tools and rapid adjustment while transferring to machining of workpieces of other standard size or configuration. Highly advanced technological possibilities of modern CNC machine tools could be explained by their high flexibility, increased rigidity, capacity and machining accuracy [4].

It should be noticed that the greatest time consumptions during machine tool adjustment is the auxiliary and preparatory components of standard time, connected with reconfiguration of fixture and set of cutting tools. Therefore, the design of flexible fixtures is an urgent task which proved by recent research [5–8]. Scientists' experience in the flexible fixture design and the tendency of computer-aided fixture design become widely used, especially notable in recent years, because of expansion of possibilities of the software [9–11]. Generally, the design of any fixture consists of stages [12]: planning of the locating chart; planning of the clamping chart; design of the fixture configuration; fixture verification. Fixture design should be realized according to production planning. Presently, the fixture design process is impossible without dynamic modeling [13]. Adjustable fixture for machining the cylinders block head based on the system of modular fixtures are represented the latest researchers in design of flexible fixtures [14]. Analysis of researches in fixture design presents that the modular fixtures should be used, as a rule, for increasing the flexibility, which are flexible only until the moment of their assembly. These fixtures, as a rule, are generally used for single-part production and small-batch manufacturing, have insufficient rigidity that make the necessity of decreasing of cutting modes and require significant setup time. Of course, the use of modularity in fixture design is effective approach. Ability to fixture adjustment while transferring to machining of parts of other standard size is the requirement of modern production [15–17]. State-of-the-art in fixture systems for the manufacture was reviewed in detail [18].

When choosing the fixture system, it should be considered the presented requirements to fixture, which relate to the increasing of the flexibility level and level of unification of fixture elements, decreasing of time consumption, caused by fixture adjustment while transferring to the machining of parts of other standard size [19]. Under conditions of modern manufacturing, characterized by instability of nomenclature and volume of product output, the key point is the rational selection of fixtures to which the following requirements are set [20, 21]: ensuring the given machining accuracy; flexibility sufficient for the machining of parts within the technical characteristic of fixture; mechanized or automated adjustments while transferring to the machining of parts of another standard size; high rigidity of parts and assemblies able to perceive the considerable cutting forces and ensure the maximum use of equipment capacity; tool availability for machining of maximum numbers of surfaces per one setup; high level of unification of parts and assemblies that ensures the decreasing of fixture cost; high functional and technological reliability of fixture and its elements; effectiveness. Main demands on designing of fixture are reduced to six groups, considering physical and precision possibilities, requirements to equilibrium state of the system, effectiveness, tool availability, and ergonomics [12]. Moreover, fixture requirements can be separated into two main groups [22, 23]: standard requirements (workspace requirements around the workpiece for each process, low-weight fixtures or the ability to use Poka Yoke) and specific requirements (tolerances, costs, short process time and ability for fast reconfiguration).

3. Materials and Methods

3.1. Fixture requirements

The fixture design process should be considered from the position that the fixture contacts with the external environment during the operation process, with the workpiece, cutting tool, machine tool and operator (Table 1). The external environment creates certain restrictions, which influence on the fixture structure and the design process.

The complication of the products, increasing their speed, accuracy and reliability lead to an increase of the requirements for accuracy and productivity of fixtures, which greatly increases the complexity of their manufacturing. A significant part of the fixtures must be made before the production of the first samples of machines, since many parts cannot be manufactured without the specified minimum of fixtures. Thus, the problem of finding ways to reduce the time and preparation expenses for production planning of new products has first-priority importance.

Fixture design is complicated and time-consuming process. Therefore, following fixture requirements were identified and should be considered during design process.

Table 1. The relationship of fixture with the external environment

Component of external environment	Characteristics
Machine Tool	Vertical/horizontal configuration
	Dimensions of working space
	Maximum rotational frequency
	Maximum load of working table
	Number of axes
	Number of cutting tools
	Machine Power
	Positioning accuracy
Workpiece	Geometrical shape
	Overall dimensions (length/width/height)
	Weight
	Work material
	Raw material form
	Material removal volume
	Stiffness
	Parameters of functional surfaces (work, locating, clamping)
	Heat treatment
	Batch size
	Annual demand
Cutting Tool	Type
	Parameters (dimensions, angles, material, etc.)
	Cutting force and torque
	Cutting modes (feed, speed, tool life, etc.)
	Tool accessibility
Worker	Qualification
	Ergonomics
	Safety

Fixtures are considered in several aspects:

- Design (structure, assembly, stiffness and strength);
- Technological (accuracy, flexibility, productivity, quality);
- Manufacturing (reliability of clamping, tool accessibility, adjustment);
- Operational (safety, maintainability, usability);
- Economical (prime cost, efficiency).

3.2. Fixtures for multiproduct manufacturing

The system of modular adjustable fixtures [19], which is based on the modular principle and possibility of adjustment of elements, meets these requirements. It is designed for locating and clamping of parts for machining on the CNC drilling-milling-boring machine tools in multiproduct manufacturing. To decrease the time consumption while fixture design, the functional modules are mostly used, not the separate parts, as on the systems of modular fixtures, which include parts and assemblies, which have the same functional application. Each module consists of elements, which are adjustable in frames of set technical characteristics by means of corresponding adjustment mechanisms. Besides, the decreasing of numbers of joints because of modular structure, in turn, increases the rigidity of fixture configurations and the accuracy of workpieces machining that is opposite to modular fixtures, in which the array of T-slots on the subplate is used that significantly decreases the rigidity of fixture in the whole. Typical structure of the system of modular adjustable fixture consists of locating and clamping module, equipped with the adjustment mechanisms of functional elements, and the supporting module.

The main advantage of the system of modular adjustable fixture before other is that it has gathered all the benefits of each fixture system and correspondingly exceeds each of them according to technical characteristics and potential during the machining of parts on the CNC drilling- milling-boring machine tools.

Different locating charts for machining of various types of parts are used. It depends on the sizes of locating surfaces and their position. To realize the typical charts of locating and clamping the adjustable locating and clamping modules are being correspondingly developed.

On locating of workpieces of prismatic parts according to the plane on the drilling-milling-boring and multipurpose machining centers, the use of adjustable locating modules [24–27] is more reasonable, the feature of which is the simultaneous movement of supports through gear (Fig. 1 a), screw (Fig. 1 b), worm (Fig. 1 c) and planetary (Fig. 1 d) adjustment mechanisms.

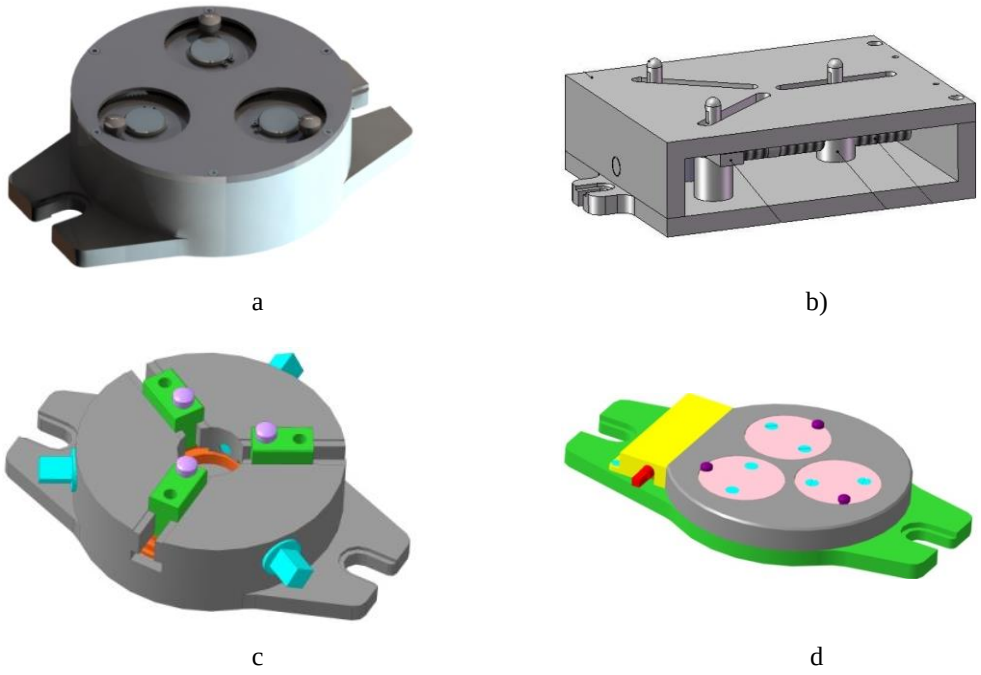


Figure 1. Adjustable locating modules for setup of prismatic parts according to the plane

For locating of workpieces in the "quadrantal angle" on the drilling-milling-boring and multipurpose machining centers, the use of adjustment locating module [28] is more reasonable, the peculiarity of which is the possibility of independent simultaneous movement of the supporting elements along the guide rails by means of screw adjustment mechanism (Fig. 2). This provides the different positions of supports, which correspond various overall dimensions in terms of workpieces within the technical characteristics.

On realization of locating charts of parts according to two planes and the hole or according to plane and two holes, the dowel pins are, as a rule, used in the fixtures. The sets of the dowel pins allow locating workpieces on the machined holes. Sets are differing from each other by range of diameters, height and number of dowel pins in the set.

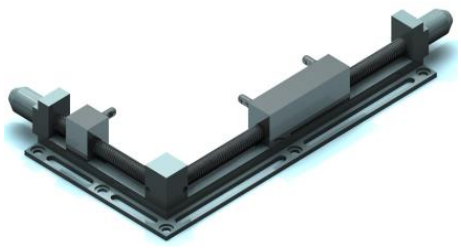
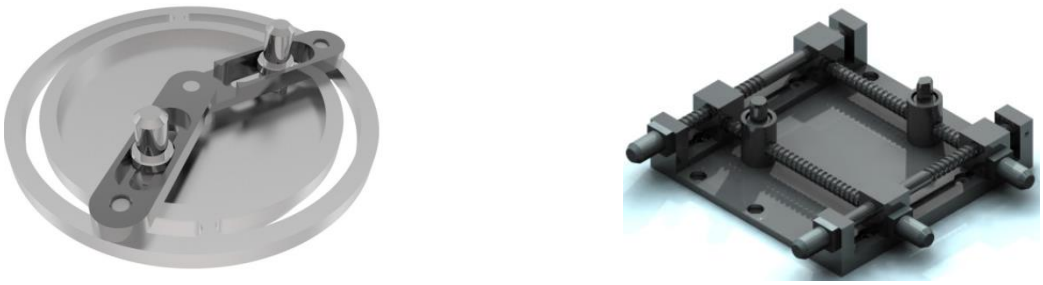


Figure 2. Adjustable locating module for locating of prismatic parts in "quadrantal angle"

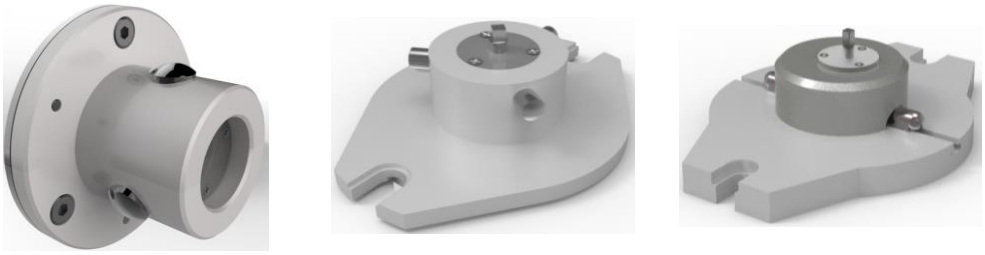
The proposed adjustable locating modules [29, 30], which could be used for locating of the following parts of automobiles: prismatic cylinder block with free location of attachable locating holes, axes of which are perpendicular to the locating plane and the connecting rods, by means of change of location and diameters of the supports. The peculiarities of the proposed fixtures are the possibility of change of the distance between dowel pins within the technical characteristics of locating modules manually (Fig. 3 a) or automatically (Fig. 3 b). It allows decreasing of time consumption for adjustment during the preparation of fixture to locating of workpiece of other standard size, increasing the flexibility and the adjustment range of locating elements, and thereof, increasing of the efficiency of use of metal-cutting machine tools under conditions of multiproduct manufacturing. By reducing the size of gaps between shafts and supporting elements, screws and supports in constructions with automatized adjustment mechanism (Fig. 3 b), it is ensured the increasing of the accuracy of adjustment of locating elements.

The special feature of locating chart of parts of disks and flanges types, as a rule, is the locating according to the plane and the central hole. Herewith, the sizes of the locating hole in parts differ that makes the production of dedicated devices or changeable units for their machining. For these charts of locating more reasonable is the use of the adjustable locating modules, the feature of which is the simultaneous movement of supports by means of use of the wedge (Fig. 4 a), gear (Fig. 4 b) and screw (Fig. 4 c) adjustment mechanisms [31–33].



a b

Figure 3. Adjustable locating modules for locating of prismatic parts according to plane and two holes



a b c

Figure 4. Adjustable locating modules for locating of parts according to internal cylindrical surfaces

It ensures different locations of supports that correspond different sizes of the locating surfaces of workpieces within the technical characteristics. The advantage of manufacturing application of these modules is the decreasing of time consumption for adjustment, increasing of flexibility and the adjustment range of locating elements.

For locating of workpieces according to the external cylindrical surface and the end, the adjustable locating-and-clamping module [34] is proposed, which could be used on the drilling-milling-boring machine tools (Fig. 5). The special feature of this module is the simultaneous movement of cams through the transmission mechanism Novikov and worm gear, and the possibility of use of one set of cams, both direct and inverse. The result of the manufacturing application of this module is the reducing of reset time, increasing of flexibility and the adjustment range of cams.

Large group of parts, machined on the drilling-milling-boring machine tools, are shafts. Grooves, flats, radial holes etc. are machined on the shafts. The main scheme of locating of shafts during the machining on these machine tools is the locating according to the double-guiding and supporting datums. It could be realized by means of locating V-blocks, which are included into the locating module [35], the special feature of which is the ability of automated adjustment in the wide range of sizes of the diameter of shafts workpieces by means of gear sectors, which separate supporting disks with the purpose of locating of the workpieces of the definite standard size. The result of the introduction into operation of this module is the reducing of time consumption for adjustment, increasing of flexibility and the wide range of adjustment of supporting discs.

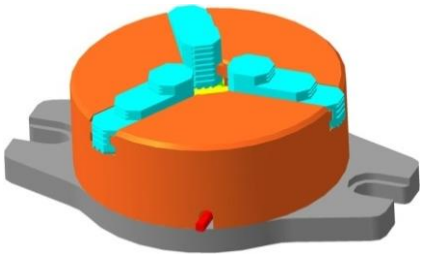
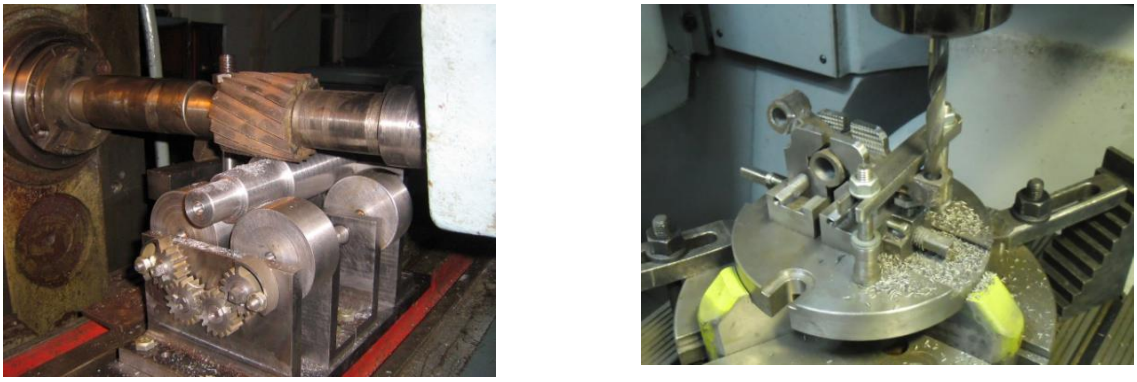


Figure 5. Adjustable locating-and-clamping module for locating of parts according to external cylindrical surfaces



a b

Figure 6. Experimental researches of modular adjustable fixtures for shafts (a) and levers (b)

All configurations of automobile transport include such details as levers, brackets, plugs, which, as a rule, differ from each other by standard sizes depending on the range of the automobile. Therefore, it is necessary to design fixtures for machining of parts of this type, which ensure the possibility of multiaxis machining of the maximum numbers of surfaces with a minimum number of setups. It is designed the adjustable locating-and-clamping module [36] for locating of lever-type parts, which allows carrying out the machining of part on the 5-axis machine tool per one. However, for locating of parts with other overall dimensions that are not within the specified range the standard sizes of module could be changed. The special feature of the proposed module is the movement of V-blocks and sliding blocks in mutually perpendicular directions that ensures locating according to the cylindrical surfaces of the central boss and lateral surfaces of levers with the simultaneous clamping by means of screw mechanism. The module could be equipped with the stepped motors to reduce the setup time and reset time. The advantage of the implementation into operation of this module is the reducing setup time and reset time, increasing of flexibility and the adjustment range of locating-and-clamping elements.

4. Results and Discussion

The proposed fixtures, which are included in the system of modular adjustable fixtures, include the parts of different types and definite group of standard sizes and allow carrying out the machining on the machine tools of drilling-milling-boring group. Performed analytical and experimental researches confirmed the sufficient accuracy of the adjustment mechanisms of the locating-and-clamping elements of fixtures.

As exemplified by machining of prismatic parts, shafts and lever-type parts by means of numerical simulation has been proved, that the rigidity of the fixture configuration is sufficient for performing the machining within the cutting modes, which are recommended by the developers of the cutting tools. The increasing of the level of fixture flexibility does not lead to deterioration of the indexes of machining accuracy that confirms the reasonability of implementing of rapid adjustable fixtures into the production process.

Experimental researches of shafts [37] and parts of lever-type parts [38] machining have demonstrated the high efficiency of the proposed engineering decisions under conditions of modern machine-building, ensuring the sufficient level of rigidity of the developed fixture on the reasonably decreasing of steel intensity and significant reducing of time (Fig. 6).

5. Conclusions

The analysis of the percentage-based ration of locating charts of parts of different types, which are included to the structure of automobiles, has been carried out. It allowed determining the directions of fixture design depending on the definite production conditions of the enterprise. The locating-and-clamping modules of the system of modular adjustable fixtures have been proposed. These configurations ensure the locating of parts according to the typical charts of locating during the machining: prismatic parts, rotational parts, complex parts, which require machining on drilling-milling-boring metal-cutting equipment.

The systematization of the adjustable locating-and-clamping modules according to locating charts and technical characteristics for parts of the definite type has been carried out. The developed locating-and-clamping modules are the definite independent mechanisms which could be placed on the table of the machine tool, subplates of the modular fixtures and adjustable and dedicated fixtures. Also, due to its independence and the wide

adjustment range one module could substitute some fixtures that reduce the prime cost of the machined parts.

The above-mentioned allows increasing the level of technological level of the enterprises-contractors, which produce the parts and separate units of automobiles, and decreasing the auxiliary and preparatory time that allows decreasing the prime cost and increasing the competitiveness of products of the definite enterprise and the industry in the whole.

The developed modules allow solving the great number of tasks, though the definite share of parts, namely: plugs, dismountable connecting rods, brackets etc., require the development of new flexible fixtures analogically to the existing for the considered types of parts. The group of the clamping modules also requires the variety, both in terms of new concepts and expansion of technological peculiarities of the existing fixtures.

Due to the rapid spread of industrial robots and expansion of their technological possibilities, in future it should be emphasized the fixture design for its using in robotic systems. It allows minimizing or even fully eliminating the physical human labor, it means to automate the production that is the most important in the automotive industry.

Acknowledgements.

This research was partially funded by the Ministry of Education and Science of Ukraine within research projects "Integrated Technology of Modular Tooling Design" (State Registration Number 0117U002252) and "Development and Implementation of Energy-Efficient Modular Separation Devices for Oil and Gas Equipment" (State Registration Number 0117U003931).

References

[1] JMTBA (2015) *Machine Tool Industry Japan 2015* (Tokyo: Japan Machine Tool Builders' Association).

[2] MacDOUGALL, W. (2015) *The Machinery & Equipment Industry in Germany. Industry Overview* (Berlin: Germany Trade & Invest).

[3] GARDNER RESEARCH (2016) *2016 World Machine-Tool Survey* (Cincinnati:Gardner Research).

[4] IVANOV, V. et. al. (2016) Design and Manufacturing Analysis of Modern Drilling-Milling-Boring Machine Tools. *Bulletin of National Technical University "Kharkiv Polytechnic Institute"* **33**(1205): 95–105 [in Ukrainian].

[5] BAKKER, O.J. et al. (2013) Recent Research on Flexible Fixtures for Manufacturing Processes. *Recent Patents on Mechanical Engineering* **6**(2): 107–121, doi: 10.2174/2212797611306020003.

[6] TOHIDI, H. and AlGEDDAWY, T. (2016) Planning of Modular Fixtures in a Robotic Assembly System. *Procedia CIRP* **41**: 252–257, doi: 10.1016/j.procir.2015.12.090.

[7] HUI, L. et al. (2016) Design and Application of Flexible Fixture. *Procedia CIRP* **56**: 528–532, doi: 10.1016/j.procir.2016.10.104.

[8] GOTHWAL, S. and RAJ, T. (2017) Different Aspects in Design and Development of Flexible Fixtures: Review and Future Directions. *International Journal of Services and Operations Management* **26**(3): 386–410, doi: 10.1504/IJSOM.2017.081944.

[9] VUKELIC, D. et al. (2011) A Rule-based System for Fixture Design. *Scientific Research and Essays* **6**(27): 5787–5802, doi: 10.5897/SRE11.1138.

[10] PAPASTATHIS, T. (2010) *Modelling and Design Methodology for Fully-Active Fixtures*. PhD Thesis. (Nottingham: The University of Nottingham).

[11] IVANOV, V. et al. (2016) Information Support of the Computer-Aided Fixture Design System. In *Proceedings of 12th International Conference on ICT in Education, Research and Industrial Applications: Integration, Harmonization and Knowledge Transfer*, ICTERI 2016, Kyiv, Ukraine, June 21-24, 2016 (online: CEUR-WS.org), 1614: 73-86.

[12] BOYLE, I. et al. (2011) A Review and Analysis of Current Computer-Aided Fixture Design Approaches. *Robotics and Computer-Integrated Manufacturing* **27**(1): 1–12, doi: 10.1016/j.rcim.2010.05.008

[13] MESHREKI, M. et al. (2008) Dynamics Modeling and Analysis of Thin-Walled Aerospace Structures for Fixture Design in Multiaxis Milling. *Journal of Manufacturing Science and Engineering* **130**(3), doi: 10.1115/1.2927444.

[14] SHEN, C. et al. (2003) *Reconfigurable Workholding Fixture*. Patent of US № 6644637.

[15] KOTOV, A.S. (2009) Adjustable Tooling for Mechanical Assembly Production. *Bulletin of National Technical University "Kharkiv Polytechnic Institute"* **2**: 31–37 [in Russian].

[16] ISHCHENKO, M.G. and MOVSHOVYCH, A.Y. (2010) Perspective Directions of Development of Modular, and Adjustable Tooling in Modern Conditions. *Machine-building* **6**: 168–178 [in Russian].

[17] BONDAR, O.V. and KRAVCHENKO, S.I. (2013) Requirements to the Design and Criteria of Evaluation of Parameters of Modular Fixtures. *Transactions of National Technical University named after Y. Kondratyuk* **5**: 49–52 [in Russian].

[18] GAMEROS, A. et al. State-of-the-art in fixture systems for the manufacture and assembly of rigid components: A review. *International Journal of Machine Tools and Manufacture* **123**: 1-21, doi: 10.1016/j.ijmachtools.2017.07.004.

[19] KARPUS', V.E. and IVANOV, V.A. (2008) Universal-composite Adjustable Machine-tool Attachments. *Russian Engineering Research* **28**(11): 1077–1083, doi: 10.3103/S1068798X08110105.

[20] KARPUS, V.E. et al. (2012) *Intensification of Manufacturing Processes* (Sumy: Sumy State University, doi: 10.13140/2.1.3953.7604 [in Ukrainian].

[21] PEHLIVAN S. and SUMMERS J. (2008) A Review of Computer-aided Fixture Design with Respect to Information Support Requirements. *International Journal of Production Research* **46**(4): 929–947, doi: 10.1080/00207540600865386.

[22] SHEN, C.-H. et al. (2006) Reconfigurable Fixtures for Automotive Engine Machining and Assembly Applications. In DASHCHENKO, A.I. (ed.), *Reconfigurable Manufacturing Systems and Transformable Factories*. 1st ed. (Berlin: Springer), pp. 155-194.

[23] FORSTMANN, R. et al. (2017) Design for Automation: The Rapid Fixture Approach. *Procedia Manufacturing* **11**: 633 – 640.

[24] IVANOV, V.O. et al. (2012) *Adjustable Locating Module*. Patent of Ukraine № 71870.

[25] KARPUS, V.E. and IVANOV, V.O. (2008) *Locating Module*. Patent of Ukraine № 31469.

[26] IVANOV, V.O. and DEHTIAROV, I.M. (2015) *Adjustable Locating Module*. Patent of Ukraine № 96399.
[27] IVANOV, V.O. et al. (2017) *Adjustable Locating-and-Clamping Module*. Patent of Ukraine № 113147.
[28] IVANOV, V.O. and KARPUS, V.E. (2011) *Adjustable Locating Module*. Patent of Ukraine № 59745.
[29] IVANOV, V.O. and KARPUS, V.E. (2011) *Adjustable Locating Module*. Patent of Ukraine № 60130.
[30] IVANOV, V.O. et al. (2012) *Adjustable Locating Module*. Patent of Ukraine № 67918.
[31] KARPUS, V.E. and IVANOV, V.O. (2008) *Adaptable Arbor*. Patent of Ukraine № 30999.
[32] IVANOV, V.O. and DEHTIAROV, I.M. (2014) *Adjustable Locating Module*. Patent of Ukraine № 95074.
[33] IVANOV, V.O. and DEHTIAROV, I.M. (2016) *Adjustable Locating Module*. Patent of Ukraine № 105296.
[34] IVANOV, V.O. et al. (2017) *Adjustable Self-centering Locating-and-Clamping Module*. Patent of Ukraine № 113148.
[35] KARPUS, V.E. and IVANOV, V.O. (2008) Adjustable V-block. Patent of Ukraine № 31416.
[36] IVANOV, V.O. et al. (2015) *Adjustable Locating-and-Clamping Module for Machining of Levers*. Patent of Ukraine № 98925.
[37] KARPUS, V.E. and IVANOV, V.A. (2012) Locating accuracy of shafts in V-blocks. *Russian Engineering Research* **32**(2): 144–150, doi: 10.3103/S1068798X1202013X.
[38] IVANOV, V. et al. (2017) Numerical Simulation of the System “Fixture – Workpiece” for Levers Machining. *The International Journal of Advanced Manufacturing Technology* **91**(1): 79–90, doi: 10.1007/s00170-016-9701-2.