Computer-Aided Positioning of Elements of the System "Fixture – Workpiece"

Vitalii Ivanov[1], Ivan Pavlenko[1], Oleksandr Liaposhchenko[1], Oleksandr Gusak[1], Vita Pavlenko[2]
{ivanov@tmvi.sumdu.edu.ua}

[1]Sumy State University, 2 Rymskogo-Korsakova St., Sumy, 40007, Ukraine;
[2]Machine-building College of Sumy State University,
17 Shevchenka Ave., Sumy, 40000, Ukraine

Abstract. The correct locating of workpieces in fixtures is an important step for ensuring the accuracy of machining. The choice of the locating chart for the specified conditions depends on the size and quality of the locating surfaces, as well as on their location. The concept of safety zone is introduced for the identification places in a workpiece, which are not desirable to use at the design stage for the contact with locating and clamping elements. The method of computer-aided positioning of functional elements of modular fixtures is proposed considering design and technological parameters of workpiece's surfaces. Integration of this technique into the computer-aided fixture design system is an effective solution for reducing time for designing fixtures for drilling-milling-boring machine tools, as well as for increasing the quality of fixtures' configuration. This approach is sufficient for fixture design for parts machining in automotive, pump, oil and gas industries. A mobile application is developed for providing positioning and visualization of the mechanical system "fixture – workpiece" using the technology of augmented reality. Case study is included to demonstrate the effectiveness and capabilities of the developed methodology.

Keywords: fixture design, modular fixture, accuracy, assembly, locating chart, workpiece, machine tool, mechanical system.

1 Introduction

Modern manufacturing industry is characterized by wide nomenclature of products and instability of production series [1]. Consequently, considerable attention is paid to fixtures, which are used for precise locating and reliable clamping of workpieces during machining on metal-cutting machine tools [2]. Considering the extended technological capabilities of modern metal-cutting machine tools, their high cost and the need for many setups in the machining of parts another standard size, the intensification of production processes is gaining rapid development [3], [4]. Thus, reducing the time required to production planning is an urgent task now, considering Industry 4.0 strategy [5], [6], [7].

Fixtures are an integral part of the closed-loop technological system "machine tool – fixture – cutting tool – workpiece". Moreover, fixtures impact on the production of competitive products in manufacturing engineering, that is confirmed by the following data [8], [9], [10]: the portion of fixtures for machining is 70–80% of the total amount of tooling; the cost of fixtures is 10–20% of the total cost of manufacturing systems; 80–90% of the time required for

MMS 2018, November 06-08, Dubrovnik, Croatia

DOI 10.4108/eai.6-11-2018.2279706

production planning correspond to the design and manufacturing of fixtures; approximately 40% of the rejected parts have dimensioning errors occurred because of the poor fixture design; 70% of new fixtures are the modification of the existing.

2 Literature Review

Experiments showed that locating errors are the major fixture-induced errors affecting the workpiece accuracy and can amount to 20–60 % of the total machining error in the extreme case [11]. The locating chart of prismatic parts for three planes (or "3-2-1 principle") provides maximum stiffness and a minimum number of fixture elements. The locating elements should be located as far apart as possible and with the condition that the mass center be located between them, which will ensure the stability of the workpiece. The clamping elements ensure the reliability of the workpiece during machining on the machine tool. The selection of optimal positions of locating and clamping elements and their placement relative to each other on the support element is an actual re-search task. Menassa and DeVries [12] proposed optimization techniques to assist in the design and evaluation of fixtures for holding prismatic workpieces. Using the minimization of the workpiece deflection at selected points as the design criterion, the design problem is determining the positions of the fixture supports. Roy and Sun [13] focused on the development of heuristic algorithms for selecting the locating and clamping positions on an automatic fixture configuration for a given workpiece for an CAFD system. Roy and Liao [14] introduced a rational approach based on the use of both qualitative and quantitative reasoning tools to plan for the “best” supporting, locating and clamping positions (on a given workpiece) to hold the workpiece rigidly and accurately during machining processes. Tao et al. [15] developed an opti-mum clamping planning approach for arbitrarily shaped workpieces based on com-putational geometry of contacting wrenches. A clamping analysis algorithm drawing on the metric of force closure is presented, in which all feasible clamping points are automatically found. Mihaylov and Nikolcheva [16] suggested a CAFD system, uses rule-based reasoning in the form of If-Then-Else rules for locating parts. This system generates modular fixtures for locating prismatic or cylindrical parts, using rules and mathematical equations. Vdovin [17] developed a method for selection of optimal locating chart of the workpiece using linear and non-linear programming. Wan et al. [18] proposed the self-assembly reasoning method according to typical feature’s assembly mode. Retfalvi [19] presented the method of automatic generation, and if required, automatic modification of such new or semi-finished elements for modular fixtures. Nelaturi et al. [20] determined the spatial locations of clamping points on the workpiece boundary using the principles of force and form closure, to ensure immobility of the fixtured part under external perturbation. Peng et al. [21] used a multi-view based modular fixture assembly model to assist information representation and management. Based on geometric constraints, they proposed a precise 3D manipula-tion approach to improve intuitive interaction and accurate 3D positioning of fixture components in virtual space. Wu et al. [22] developed algorithms for analyzing accessibility and fixture ability and generating feasible clamp positions of a fixture plan are developed based on several new concepts. Additionally, a significant contribution to the fixture design can play artificial neural networks, the comprehensive use of which for solving a wide range of engineering problems is considered by Pavlenko et al. [23].

3 Research Methodology

3.1 Aim of the research

The aim of the paper is to develop a methodology allows computer-aided positioning of functional elements of fixtures considering the design and technological parameters of the workpiece. Integration of this technique into the system of computer-aided fixture design [24] based on process-oriented approach [25] is an effective solution for reducing the time for fixture design for drilling-milling-boring machine tools, as well as for improving the quality of the fixtures‘ components.

3.2 Strategy of the positioning

The main input information for positioning are codes of the functional elements (locating, clamping, supporting) of the fixture, from which fixtures are planned to com-pose parameters of functional surfaces of the workpiece.

The algorithm of the spatial positioning of structural elements of the system “fixture – workpiece” is carried out in a following sequence:

- positioning of the supporting element in the global coordinate system;
- positioning of locating elements on the supporting element;
- positioning of clamping elements on the supporting element;
- positioning of the workpiece.

In this paper, the typical scheme of locating on three planes (3-2-1) is considering, which is inherent to prismatic parts. This scheme allows depriving the workpiece of six degrees of freedom, which is realized through six locating elements (L1, L2, L3, L4, L5, L6). The primary datum is realized by the elements L1, L2, L3, the secondary datum – by elements L4, L5, and the tertiary datum – by the element L6. The work-piece is fixed in a definite position by the clamping element C1.

3.3 Positioning of supporting element

When positioning the supporting element, the rules and requirements for its “real” locating on the worktable of the machine tool should be followed. Consequently, the supporting element should be in the center of the machine tool’s worktable under the condition that side surfaces are parallel. The direction of the series of holes of the supporting element should be coincided with the direction of T-shape slots of the machine tool’s worktable.

Positioning of the supporting element S1 is realized in the global coordinate system XYZ with the coincidence of the central point of the lower surface of the supporting element S1 with the XY-plane at the point O ($X = 0$; $Y = 0$; $Z = 0$).

3.4 Positioning of locating elements

The supporting element for positioning of locating and clamping ones has a defined rectangular array of holes with a defined step. Consequently, positioning is carrying out by discrete values.

Positioning of the locating elements is realized in the plane XY, therefore, is determined by the coordinates of two axes X and Y for each element. In the automated positioning of the locating elements, the basic principles of the theory of locating of parts should be followed. For the locating chart “3-2-1”, the coordinates for the elements are determined by the following order: primary datum (3 elements); secondary datum (2 elements); tertiary datum (1 element).

The primary datum is related to the surface with the maximum area. According to the theory of locating, it realized by three locating elements (L1, L2, L3), which are placed as an equilateral triangle. To ensure the stability of the workpiece with overall dimensions $L_W \times B_W$ in fixture, this triangle should be circumscribed by a circle of the maximum radius R_j limited to the half of the workpiece's width $B_W/2$ (Fig. 1).

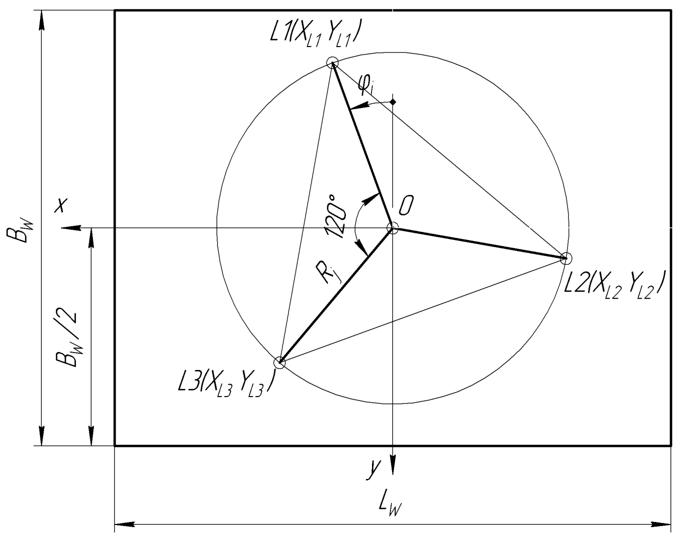


Fig. 1. Locating chart of elements L1, L2, L3 realizing the primary datum.

Positioning of the locating elements L1, L2, L3 is realized using the procedure of the nested loop: radius Rj of the circumscribed circle, and rotation angle φi for vertices of the triangle considering the conditions of avoiding safety zones. The corresponding algorithm is presented in Fig. 2.

Since the algorithm provides the calculation of theoretical coordinates that do not correspond to the actual coordinates of the grid of the holes for the supporting element, coordinates of the nearest hole should be determined, in which the locating element will be placed. It is needed to find the minimum distance Δ between the calculation point and the real holes, that is realized by the algorithm of the uniform search for the function of discrete arguments considering the condition of avoiding the safety zones. Coordinates Z of the locating elements L1, L2, L3 are equal the height of the supporting element S1.

The secondary datum is devoted to the surface with the maximum length. This datum eliminates the workpiece of two degrees of freedom. Positioning the locating elements (L4, L5) in the directions X and Y is realized by the algorithm presented in Fig. 3.

Coordinates Z of locating elements L4, L5 are determined by the height of the workpiece and supporting element S1.

The tertiary datum with the plane surface deprives the workpiece of one degree of freedom. The locating element L6, as a rule, is installed in the center of the workpiece, and hence the coordinate YL6 = 0. The coordinate of locating element L6 in the direction of Z-axis depends on the height of the workpiece and supporting element S1.

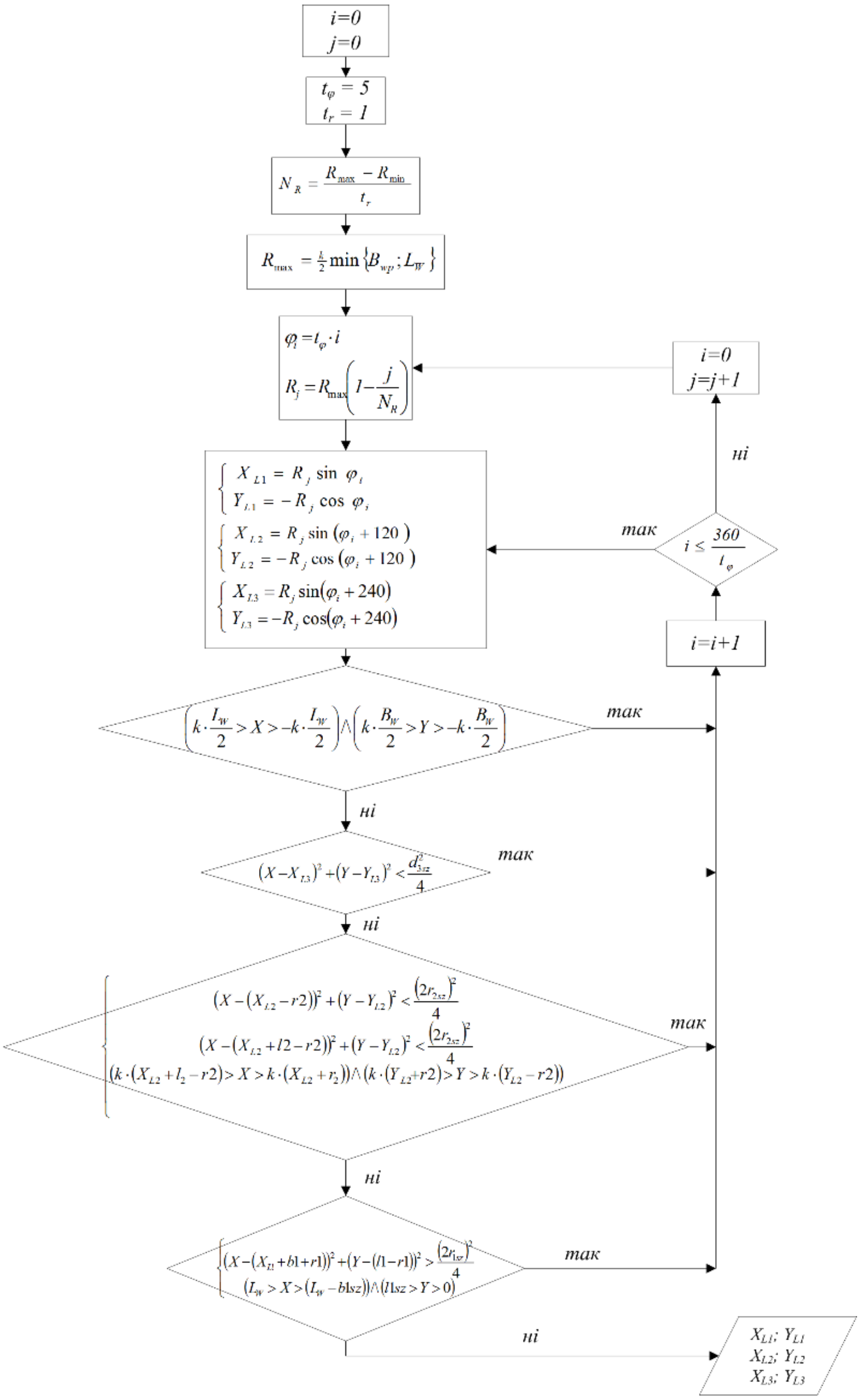


Fig. 2. Algorithm for positioning of locating elements L1, L2, L3 realizing the primary datum.

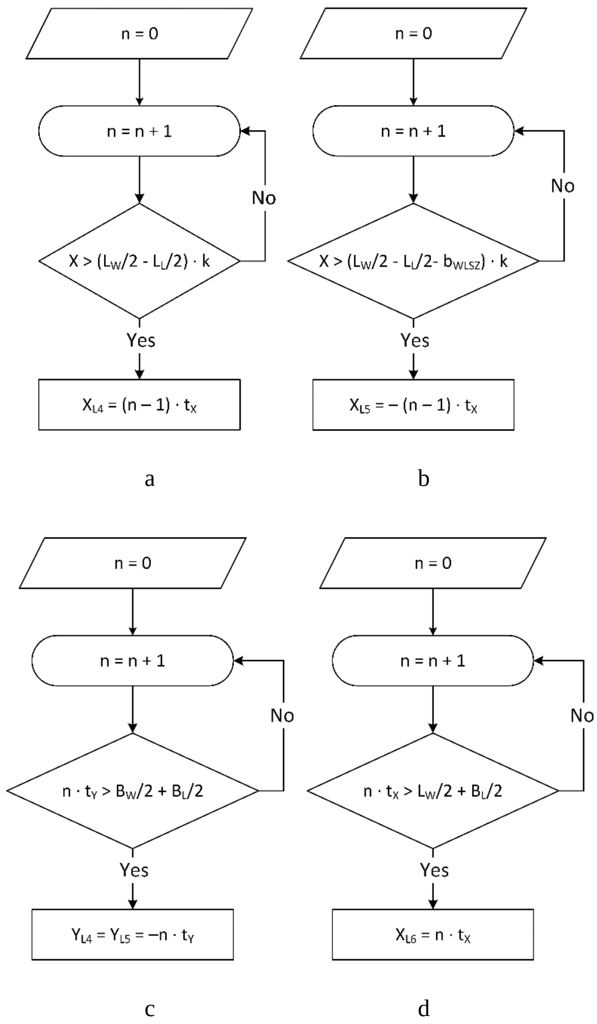


Fig. 3. Algorithm for positioning locating elements L4, L5, L6 in axis X and Y realizing the secondary datum.

3.5 Positioning of clamping elements

Clamping elements are devoted for reliable fixing of the workpiece in a fixture and deprivation of its movements during machining. Consequently, the choice of locations of clamping forces is an important problem in the field of fixture design. The main statements of the manufacturing engineering shows that the location of the clamping element should be chosen in such approach, that the clamping forces do not lead to the decrease the stiffness of the system "fixture – workpiece".

Clamping elements, analogously to locating ones, are positioned under the discrete values through holes in the supporting element. This procedure is realized in XY-plane by the developed algorithms in directions X and Y (Fig. 4).

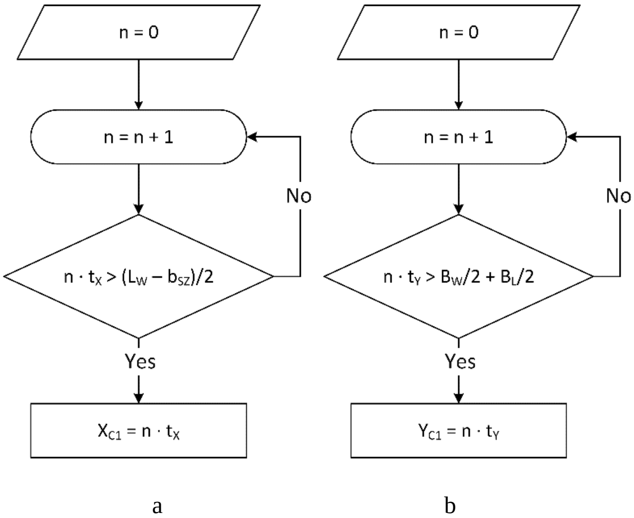


Fig. 4. Algorithm for positioning the clamping element C1 in axis X and Y.

3.6 Positioning of the workpiece

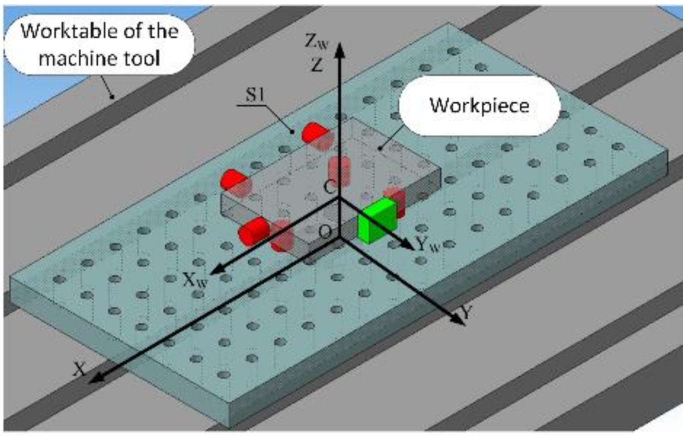
When positioning the workpiece, it is necessary to ensure the coincidence of the point C (center of the basic surface of the workpiece) with the global coordinate system XYZ in XY-plane (X = 0; Y = 0). The value of positioning the workpiece in the direction Z depends on the height of the supporting and locating elements (Fig. 5 a). In the case, when the fixture configuration uses adjustable locating and clamping elements, the contacts with the workpiece in XY-plane are provided by regulating the corresponding elements within a given range.

When using non-adjustable locating and clamping elements, it is necessary to correct the position of the workpiece toward the contact with the functional elements L4, L5, L6. The corresponding corrections are ΔX_W, ΔY_W (Fig. 5 b). As a result, the point *C* moves to a point $C^{/}$ with coordinates determined by the following formulas:

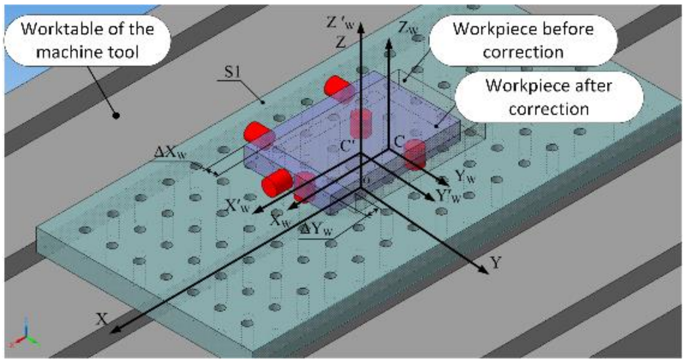
$$X_{C'} = X_c \pm \Delta_{X_W};\ Y_{C'} = Y_c \pm \Delta_{Y_W};$$

where sign "+" corresponds to the axis direction, and sign "–" corresponds to the direction against the axis.
The correction movement of the workpiece on the values ΔX_W, ΔY_W in the directions of axes *X* and *Y* respectively are determined by the following formulas:

$$\Delta X_W = n \cdot t_x - \frac{L_W}{2} - \frac{B_L}{2};\ \Delta Y_W = -n \cdot t_y + \frac{B_W}{2} + \frac{B_L}{2}.$$



a



b

Fig. 5. Graphical interpretation of positioning for the workpiece using adjustable (a) and non-adjustable (b) functional elements.

4 Results

4.1 Analysis of the workpiece

The part (Fig. 6) requires drilling and milling machining. The whole set of functional surfaces of the workpiece can be divided into: work; locating; clamping. Work surfaces are the surfaces that will be shaped during machining: through hole, blind keyway, ledge. The locating chart for prismatic parts is used. Secondary and tertiary datums make an angle 90°. The surface under the clamping elements is the edge of the workpiece, which is parallel to the secondary datum.

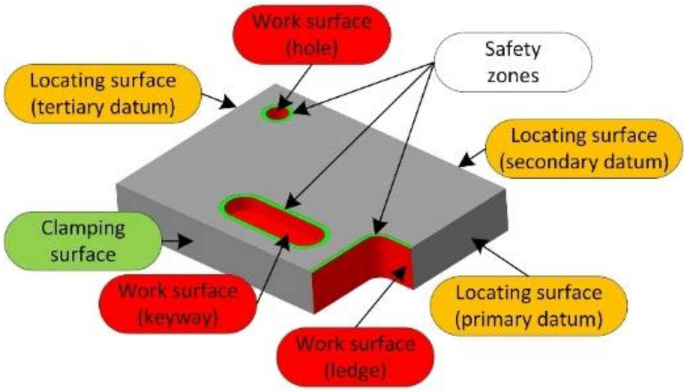


Fig. 6. Identification of workpiece's functional surfaces.

4.2 Identification of safety zones

It is important to provide the maximum tool accessibility for machining, that is, functional elements (locating, clamping) should not block the workpiece machining. According to the theory of the locating of parts, it is not desirable to position the functional elements close to the work surfaces, therefore the concept of "safety zone" is proposed, which overlaps the dimensions of the work surface with a certain coefficient (Fig. 6), the magnitude of which is substantiated for design and technological considerations. Thus, the functional elements should be positioned outside the safety zone.

4.3 Computer realization

For the workpiece locating in the fixture, standard functional elements, which are part of the modular fixture set of Carr Lane Manufacturing Co. are used. The proposed mathematical model allows to automatize the fixture design process, helping to reduce the time for the production planning, and increasing the quality of the developed design solutions. The implementation of the proposed algorithms allows to provide an integrated approach to all structural elements of the system "fixture – workpiece" for the given production conditions on an example of the investigated workpiece (Fig. 7).

A mobile application based on the augmented reality technology using the "Vuforia" system has been developed. This technology is implemented by installing a mobile application on a smartphone or tablet with Android OS. The application contains a menu system that allows the user to select functional elements from the database. Fig. 8 introduces the positioning fixture in the global coordinate system XYZ, the "Supports" menu allows to view available locating elements, which can be located on the supporting element. Designed fixture includes six locating elements and one clamping element. The application allows to create the effect of the presence of a real fixture on the working table of the tooling engineer.

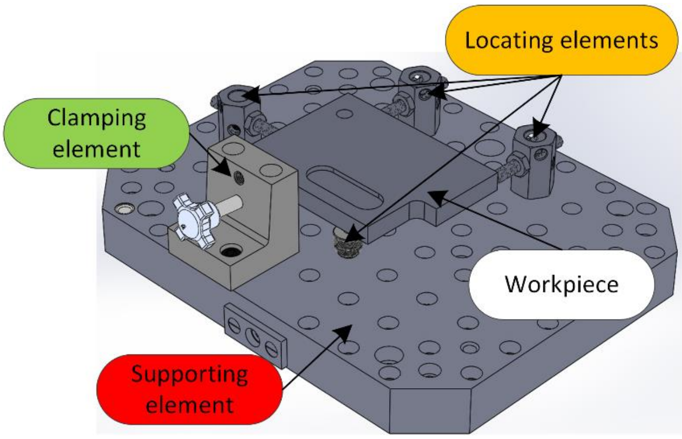


Fig. 7. Fixture configuration.

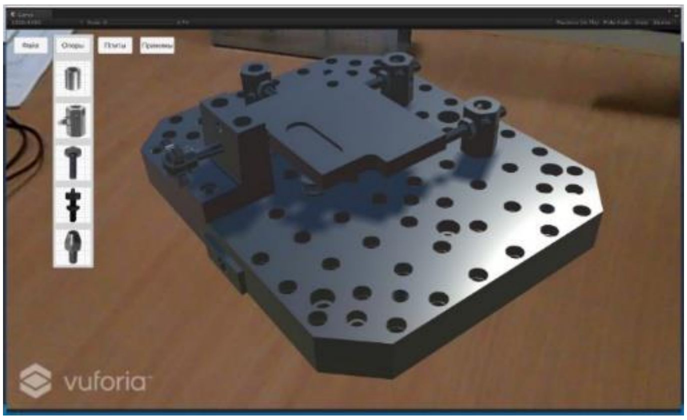


Fig. 8. Visualization of the system “fixture – workpiece” using augmented reality.

Conclusions

The design and technological features of the workpiece are analyzed, which are the fundamentals for the computer-aided fixture design. The term “safety zone” was introduced. The safety zones on the workpiece allow at the design stage to identify places on the workpiece, which is not desirable to use for contact with locating and clamping elements.

The method of positioning elements of the system “fixture – workpiece” is developed, considering the geometric parameters of the work surfaces, which allows to automatically select the optimal contact points of the workpiece with functional elements and can be used in computer-aided fixture design system.

The mobile application that provides the positioning and visualization of the system “fixture – workpiece” is developed based on the augmented reality technology and implemented with OS Android.

Acknowledgements

This research was partially funded by the Ministry of Education and Science of Ukraine (projects No. 0117U002252 and No. 0117U003931).

References

[1] Rewers, P., Osiński, F., Żywicki, K.: Classification of products in production levelling. In: Machado J., Soares F., Veiga G. (eds) Innovation, Engineering and Entrepreneurship. HELIX 2018. Lecture Notes in Electrical Engineering, Vol. 505, pp. 411–417, Springer, Cham, https://doi.org/10.1007/978-3-319-91334-6_56 (2019).
[2] Karpus, V.E., Ivanov, V.A.: Locating accuracy of shafts in V-blocks. Russian Engineering Research 32(2), pp. 144–150, https://doi.org/10.3103/S1068798X1202013X (2012).
[3] Balog, M., Husar, J.: Methodical framework of flexibility production evaluation in terms of manufacturing plant. Key Engineering Materials, Vol. 669, pp. 568-577, https://doi.org/10.4028/www.scientific.net/KEM.669.568 (2016).
[4] Trojanowska, J., Kolinski A., Galusik D. et al: A methodology of improvement of manufacturing productivity through increasing operational efficiency of the production process. In: Hamrol, A., Ciszak, O., Legutko, S., Jurczyk, M. (eds.) Advances in Manufacturing. Lecture Notes in Mechanical Engineering, pp. 23–32, Springer, Cham, https://doi.org/10.1007/978-3-319-68619-6_3 (2018).
[5] Monka, P., Monkova, K., Edl, M., Zidkova, H., Duchek, V. Fundamental requirements for CAPP software design focusing on Industry 4.0 specific features. In: Ni J., Majstorovic V., Djurdjanovic D. (eds.) Proceedings of 3rd International Conference on the Industry 4.0 Model for Advanced Manufacturing. AMP 2018. Lecture Notes in Mechanical Engineering, pp. 146–155, Springer, Cham, https://doi.org/10.1007/978-3-319-89563-5_11 (2018).
[6] Kozłowski, J., Sika, R., Górski, F., Ciszak, O. Modeling of foundry processes in the era of Industry 4.0. In: Ivanov V. et al. (eds.) Advances in Design, Simulation and Manufacturing. DSMIE 2018. Lecture Notes in Mechanical Engineering, pp. 62–71, Springer, Cham, https://doi.org/10.1007/978-3-319-93587-4_7 (2019).
[7] Peraković, D., Periša, M., Sente, R.E. Information and communication technologies within Industry 4.0 concept. In: Ivanov V. et al. (eds.) Advances in Design, Simulation and Manufacturing. DSMIE 2018. Lecture Notes in Mechanical Engineering, pp. 127–134, Springer, Cham, https://doi.org/10.1007/978-3-319-93587-4_14 (2019).
[8] Ivanov, V., Mital, D., Karpus, V. et al.: Numerical simulation of the system "fixture – workpiece" for lever machining. The International Journal of Advanced Manufacturing Technology 91(1-4), pp. 79–90, https://doi.org/10.1007/s00170-016-9701-2 (2017).
[9] Bi, Z.M., Zhang, W.J.: Flexible fixture design and automation: Review, issues and future directions. International Journal of Production Research 39(13), pp. 2867–2894, https://doi.org/10.1080/00207540110054579 (2001).
[10] Wang, H., Rong, Y., Li, H., Shaun, P.: Computer aided fixture design: Recent research and trends. Computer-Aided Design 42(12), pp. 1085–1094, https://doi.org/10.1016/j.cad.2010.07.003 (2010).
[11] Zhu, S.W., Ding, G.F., Ma, S.W. et al.: The International Journal of Advanced Manufacturing Technology 67(5-8), pp. 1423–1432, https://doi.org/10.1007/s00170-012-4578-1 (2013).
[12] Menassa, R. J., DeVries, W. R.: Optimization methods applied to selecting support positions in fixture design. Journal of Engineering for Industry – Transactions of the ASME 113(4), pp. 412–418 (1991).
[13] Roy, U., Sun, P.-L.: Selection of preliminary locating and clamping positions on a workpiece for an automatic fixture design system. Computer Integrated Manufacturing Systems 7(3), pp. 161–172, https://doi.org/10.1016/0951-5240(94)90035-3 (1994).

[14] Roy, U., Liao, J.: Geometric reasoning for re-allocation of supporting and clamping positions in the automated fixture design system. IIE Transactions 31(4), pp. 313–322, https://doi.org/10.1023/A:100760921 (1999).
[15] Tao, Z. J., Kumar, A. S., Nee, A. Y. C.: A computational geometry approach to optimum clamping synthesis of machining fixtures. International Journal of Production Research 37(15), pp. 3495–3517, https://doi.org/10.1080/002075499190158 (1999).
[16] Mihaylov, O., Nikolcheva, G.: An integrated RBR fixture design system. In: Mudrik, R., Vit, O., Basova, P. et al. (eds.) CBU International Conference on Innovations in Science and Education, Vol. 5, pp. 1175–1180, http://dx.doi.org/10.12955/cbup.v5.1091 (2017).
[17] Vdovin, A.V.: Automated selection of optimal setup chart of workpiece in fixture and design realization using CAD systems. PhD thesis. Bryansk State Technical University, Bryansk (2003).
[18] Wan, N., Wang, Z., Mo, R.: An intelligent fixture design method based on smart modular fixture unit. The International Journal of Advanced Manufacturing Technology 69(9-12), pp. 2629–2649 http://dx.doi.org/10.1007/s00170-013-5134-3 (2013).
[19] Retfalvi, A.: Fixture design system with automatic generation and modification of complementary elements for modular fixtures. Acta Polytechnica Hungarica 12(7), pp. 163–182 (2015).
[20] Nelaturi, S., Rangarajan, A., Fritz, C., Kurtoglu, T.: Automated fixture configuration for rapid manufacturing planning. Computer-Aided Design 46, pp. 160–169, http://dx.doi.org/10.1016/j.cad.2013.08.028 (2014).
[21] Peng, G., Wang, G., Liu, W., Yu, H.: A desktop virtual reality-based interactive modular fixture configuration design system. Computer-Aided Design 42(5), pp. 432–444, http://dx.doi.org/10.1016/j.cad.2009.02.003 (2010).
[22] Wu, Y., Gao, S., Chen, Z.: Automated modular fixture planning based on linkage mechanism theory. Robotics and Computer-Integrated Manufacturing 24(1), pp. 38–49, http://dx.doi.org/10.1016/j.rcim.2006.06.003 (2008).
[23] Pavlenko I., Trojanowska J., Ivanov V., Liaposhchenko O.: Scientific and methodological approach for the identification of mathematical models of mechanical systems by using artificial neural networks. In: Machado J., Soares F., Veiga G. (eds.) Innovation, Engineering and Entrepreneurship. HELIX 2018. Lecture Notes in Electrical Engineering, Vol. 505, pp. 299–306, Springer, Cham, https://doi.org/10.1007/978-3-319-91334-6_41 (2019).
[24] Ivanov, V., Vashchenko, S., Rong, Y.: Information support of the computer-aided fixture design system. In: Proceedings of 12th International Conference ICTERI'2016, Vol. 1614, pp. 73–86, CEUR-WS, online CEUR-WS.org, http://ceur-ws.org/Vol-1614/paper_37.pdf (2016).
[25] Ivanov V. Process-oriented approach to fixture design. In: Ivanov V. et al. (eds.) Advances in Design, Simulation and Manufacturing. DSMIE-2018. Lecture Notes in Mechanical Engineering, pp. 42–50, Springer, Cham, https://doi.org/10.1007/978-3-319-93587-4_5 (2019).