Flexible Fixtures for Parts Machining in Automobile Industry

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Abstract. Fixtures play an essential role in production of high-quality and competitive products, especially under conditions of multiproduct manufacturing, which requires quickly re-equipment while transferring to the machining of parts of other nomenclature. Nowadays, the multiproduct manufacturing is the basic form of organization in the manufacturing and automobile industries. The article describes the ways of increasing of machining efficiency of parts of automobile industry at the contracting organizations, which are parts of automakers or work closely with them. For increasing the machining efficiency through the use of approaches to intensification of production, and also for performed analysis of locating charts for the majority of parts, which are included to the construction of machines, the principally new constructions of functional modules of modular adjustable fixtures for locating and clamping of parts are used. Use of the proposed construction with the possibility of automatized adjustment ensures the spreading of technological possibilities of metal-cutting equipment, decreasing of preparatory time and setup time, and therefore, assists improving of the efficiency of production planning.

Keywords: automobile, fixture design, modular fixture, adjustable fixture, functional module, machining, efficiency, production planning.

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

MMS CONFERENCE 2017, November 22-24, Starý Smokovec, Slovakia

DOI 10.4108/eai.22-11-2017.2274155

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.

In this regard, much attention is paid to the fixtures, which are used for locating of automobiles parts. It should be noticed that taking into account the expansion of technological possibilities 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 Requirements to fixtures

The greatest nomenclature of parts of machine-building 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. Therefore, the main direction of efficiency increasing of parts machining of automobiles is the automation of production processes, performed by means of use of CNC machine tools and rapid re-equipment 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 [1]. Thus, the adjustment of the machine tool for machining of new batch of workpieces is carried out by means of changing of CNC data and tooling. It should be noticed that the greatest time consumptions during adjustment is the auxiliary and preparatory components of standard time, connected with replacement of fixture and set of cutting tool. Therefore, the design of flexible fixtures is an urgent task which proved by recent research [2], [3], [4], [5].

Scientists' experience in the fixture design [6], [7] allow suggesting that flexible fixtures and the tendency of computer-aided fixture design become widely used, especially notable in recent years, because of expansion of possibilities of the software. Generally, the design of any fixture consists of stages [8]: planning of the locating chart; planning of the clamping chart; design of the fixture configuration; fixture verification. Authors [9], [10] for development of fixture configuration for 5-axis machining use hybrid heuristic algorithm with intellectual function of variants selection. Work [11] describes the integrated system of development of fixtures for machining of parts with minimum tolerances. Work of Nalbandh and Rajyaguru [12] is devoted to use of "genetic algorithm" of design and optimization of fixtures, based on the probabilistic methods of calculation. Presently, the design process of fixture is impossible without dynamic modeling, which is presented in detail in work [13],

devoted to the aerospace industry. However, this is true for all areas of machine-building industry. Work [2] describes the latest researches in the area of design of flexible fixtures and presents adjustable constructions of fixtures for machining the cylinders block head [14] on the basis of the system of modular fixtures. 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 in the automobile industry. Ability to fixture adjustment while transferring to machining of parts of other standard size is the requirement of modern production [15], [16], [17].

When choosing the fixture system, it should be taken into account the presented requirements to fixture, which are connected with 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. The system of modular adjustable fixtures [18] meets these conditions, which is based on the assembly-modular principle of building of fixture configurations and possibility of adjustment of elements, in particular automatized. The system of modular adjustable fixture is designed for locating and clamping of parts while machining on the CNC drilling-milling-boring machine tools under conditions of multiproduct manufacturing. In order to decrease the time consumption while forming fixture components, 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 in itself 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.

3 Analysis of locating charts of parts on 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.

Prismatic parts (54% of all parts), flat parts (5%) and complex parts such as levers, connecting rods, brackets, bars etc. (7%) and rotational parts (34%) [19] are machined on the CNC drilling-milling-boring machine tools.

Prismatic parts during the machining on the metal-cutting machine tools are located according to the following typical locating charts: according to three planes; according to two planes and a hole; according to plane and two holes (Fig. 1). The character feature of these schemes is that one of the flat surfaces (primarily the largest) is used as a locating datum ensuring the sufficient stability, convenience of clamping and prevention of vibrations during the machining.

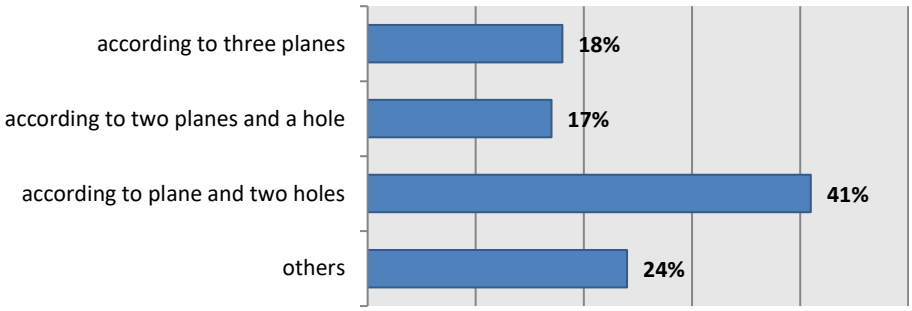


Fig. 1. Distribution of prismatic parts according to locating charts.

In the parts of machine-building industry, especially during the production of automobile parts, the necessity of machining of radially situated holes in the discs and flanges (for example hole under bolts in the covers) are commonly used. Setup of parts of flanges and discs type is mainly performed according to the following locating charts (Fig. 2): according to butt and internal cylindrical surface; according to butt and external cylindrical surface; according to butt, internal cylindrical surface and keyway; according to butt, external cylindrical surface and keyway; according to butt and splined hole. The characteristic feature of these charts is the compulsory presence of flat and cylindrical surfaces, which together deprive the part of five degrees of freedom, leaving only the possibilities of angular rotation on the axis Z. The last degree of freedom is removed, as a rule, by means of constructive elements (holes, slots etc.) on the cylindrical surfaces or on the butt of parts.

Also significant group of parts that are machined on the drilling-milling-boring machine tools are shafts. Grooves, flats and radial holes are machined on the shafts. Results of quantitative analysis of manufacturing processes of shafts production during the drilling-milling-boring operations have proved that the parts locating of the present type is carried out mostly according to the following locating charts (Fig. 3): according to external cylindrical surfaces and the butt; according to external cylindrical surfaces, the butt and radially situated element; in the centers. Other charts are separate cases caused, as a rule, by constructive peculiarities of the separate parts. The character feature of these charts is the obligatory presence of one long and two short cylindrical surfaces, which are situated on the length $l > d$ and the butt surface that together deprive

the part of five degrees of freedom, leaving only the possibility of angular rotation. The last degree of freedom is removed in the same way as previously considered flanges and discs.

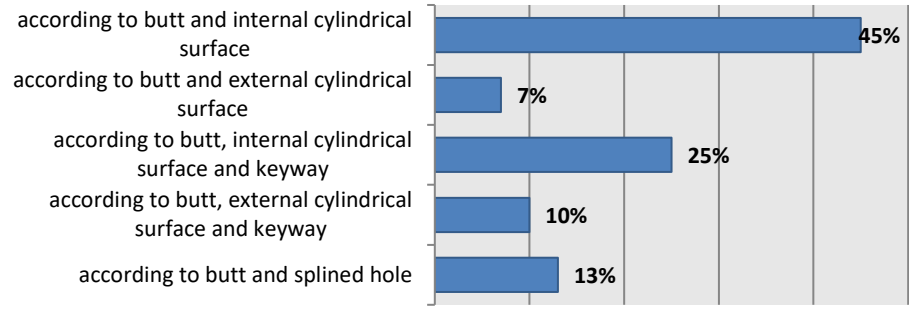


Fig. 2. Distribution of rotational parts (flanges and discs) type according to locating charts.

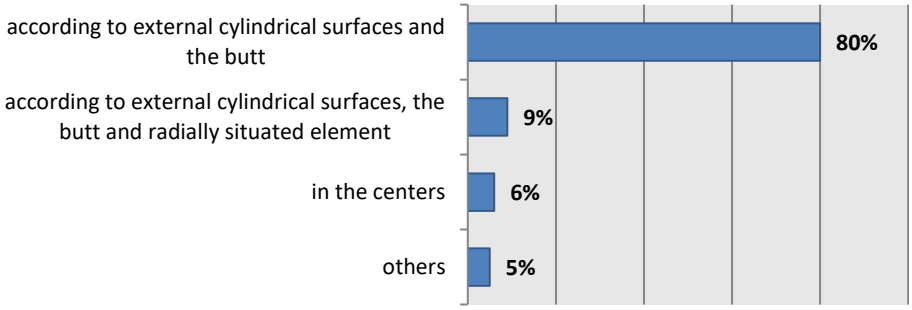


Fig. 3. Distribution of rotational parts (shafts) according to locating charts.

The above-considered charts in its majority are traditional and well known, thought the parts of more complicated form (levers, brackets and piston rods), parts of curvilinear surfaces of cam type etc., which are one of the main parts of automobile units, are also machined on the drilling-milling-boring machine tools. For these and the similar parts, the traditional locating charts are not suitable, so it is necessary to develop the individual approach to the fixture design, ensuring the correspondence to requirements of designer.

4 Adjustable functional modules

4.1 Adjustable locating modules for locating of prismatic parts

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 [20], [21], [22], [23] is more reasonable, the feature of which is the simultaneous movement of supports through gear (Fig. 4 a), screw (Fig. 4 b), worm (Fig. 4 c) and planetary (Fig. 4 d) adjustment mechanisms. In this case, different positions of supports are ensured, which correspond various overall dimensions in terms of workpieces within the technical characteristics (Table 1). The result of the implementation into operation of these modules is the reducing of time consumption for adjustment, increasing of flexibility and the range of adjustment of locating elements.

To increase the efficiency of use of adjustable locating modules the sets of supports with different locating surfaces (cylindrical, flat and knurled), which correspond the definite state of the locating datum of workpiece, could be used.

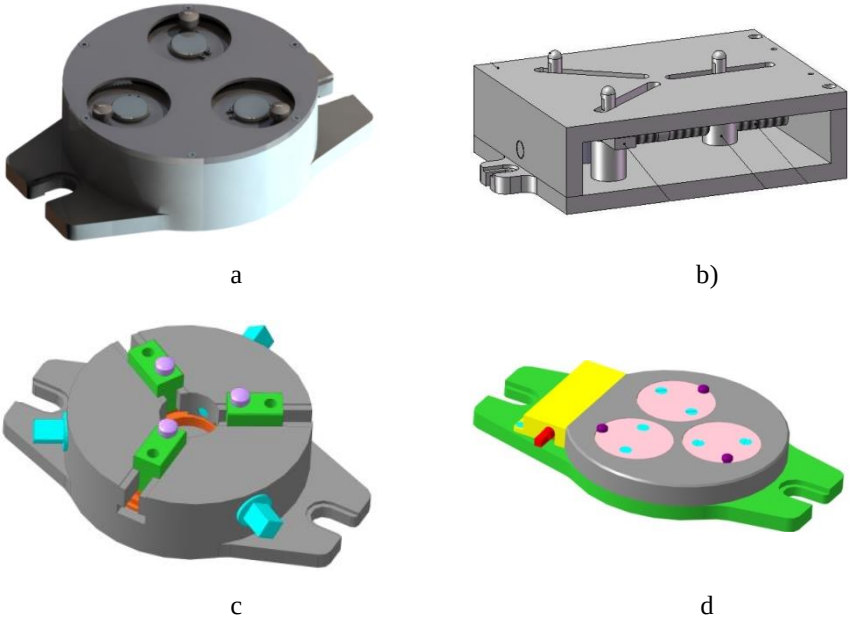


Fig. 4. Adjustable locating modules for setup of prismatic parts according to the plane.

The accuracy of adjustment of locating elements of modules depends on the type of adjustment mechanism and the value of the overall gap of the totality of mechanical transmissions, which connect the locating elements and the drive shaft. Reset time of the locating elements of modules depends on the type of adjustment mechanism, type of drive (manual/automatic) and overall dimensions of locating elements.

Table 1. Technical features of the adjustable locating modules

Parameters of locating modules			Overall dimensions in terms of the workpiece, mm		Diameter of the locating elements, mm	Setup time, sec.
Fig.	Overall dimensions, mm	Weight, kg	min.	max.		
4 a	280x200x75	10	80x80	200x200	6–20	3–10
4 b	400x220x80	18	40x40	220x180	10	5-15
4 c	300x225x90	14	60x60	200x200	6–20	3–10
4 d	460x280x60	24	50x50	230x230	6–20	5–15
5	570x330x72	11	80x150	250x500	6–25	5–15
6 a	350x350x85	16	80x80	300x300	10–50	5–15
6 b	360x360x95	20	80x80	220x220	16–50	3-10

For locating of workpieces in the “quadrantal angle” on the drilling-milling-boring and multipurpose machining centers, the use of adjustment locating module [24] 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. 5). This provides the different positions of supports, which correspond various overall dimensions in terms of workpieces within the technical characteristics (Table 1). According to this scheme, the locating of the following prismatic parts is carried out: cylinder units and other parts of prismatic form, which do not have holes. Locating module could be installed as on the table of machine tool, so as on the subplates, which are included into the different sets of modular fixtures and configurations of adjustable and dedicated fixtures. In case of necessity of workpiece locating with stepped locating surfaces, it is applicable the possibility of manual adjustment of the value of supports extension to a certain size. The result of manufacturing application of such a module is the reducing of reset time, increasing of flexibility and the range of adjustment of locating elements, and decreasing of the quantity of elements of modular fixture systems.

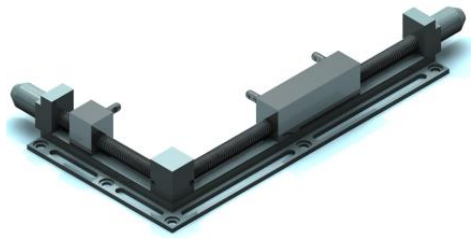
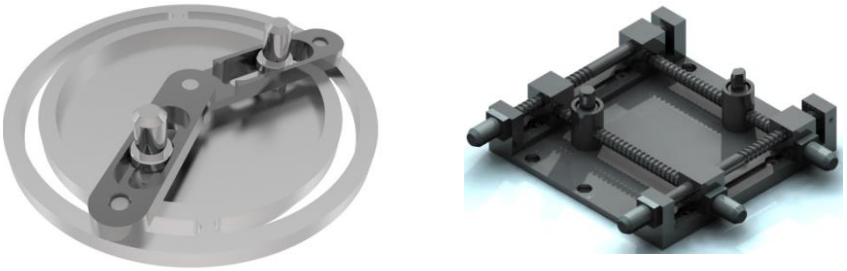


Fig. 5. Adjustable locating module for locating of prismatic parts in “quadrantal angle”.

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 locating

surfaces of holes. Sets are differs from each other by range of diameters, height and number of dowel pins in the set.

The proposed adjustable locating modules [25], [26], 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 (Table 1) manually (Fig. 6 a) or automatically (Fig. 6 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. 6 b), it is ensured the increasing of the accuracy of adjustment of locating elements.

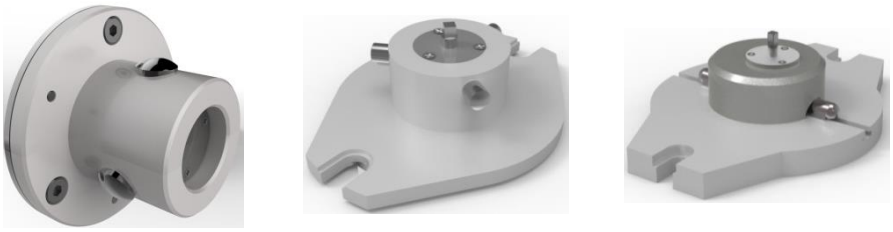


a b

Fig. 6. Adjustable locating modules for locating of prismatic parts according to plane and two holes.

4.2 Adjustable locating modules for locating of disks, flanges, bushes

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 [27], [28], [29], the feature of which is the simultaneous movement of supports by means of use of the wedge (Fig. 7 a), gear (Fig. 7 b) and screw (Fig. 7 c) adjustment mechanisms. It ensures different locations of supports that correspond different sizes of the locating surfaces of workpieces within the technical characteristics (Table 2). 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.



a b c

Fig. 7. Adjustable locating modules for locating of parts according to internal cylindrical surfaces.

Locating module (Fig. 7 a) could be used on lathes and drilling-milling-boring machine tools on locating according to the internal cylindrical surface. Centering and clamping of the workpiece is carried out by means of simultaneous movement of plungers on the T-slots, situated at an angle on the surface of clamping wedge until tight the wall of the hole of part. Thus the clamping of workpieces of different diameters is realized.

Adjustment of the adjustable locating modules (Fig. 7 b, 7 c) to the required size is carried out by means of rotation of the drive shaft, which set in motion pistons through the adjustment mechanism, which simultaneously moving to the required value ensuring centering of workpiece relatively the axis of locating module.

Table 2. Technical characteristics of the locating modules for locating of parts according to internal cylindrical surfaces

Fig.	Minimum sizes of the workpiece, mm	Maximum sizes of the workpiece, mm	Maximum weight of the workpiece, kg	Diameter of the locating elements, mm	Setup time, sec.
7 a	Ø50xØ40x50	Ø200xØ48x100	25	10–20	10–15
7 b	Ø140xØ130x50	Ø250xØ180x200	100	12	10–15
7 c	Ø130xØ120x30	Ø300xØ220x200	100	12	10–15

For locating of workpieces according to the external cylindrical surface and the end, the adjustable locating-and-clamping module [30] is proposed, which could be used on the drilling-milling-boring machine tools (Fig. 8). 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. Herewith, different locations of cams are ensured, which correspond the overall dimensions of workpieces dxl = Ø10x20…Ø220x100 mm. The maximum weight of the machined workpiece is 100 kg, the setup time, notably the transferring of cams from minimum

till maximum diameter, makes 10…15 sec. depending on their initial position. The result of the manufacturing application of this module is the reducing of reset time, increasing of flexibility and the adjustment range of cams.

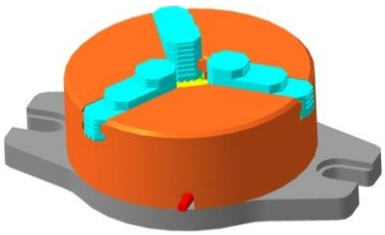


Fig. 8. Adjustable locating-and-clamping module for locating of parts according to external cylindrical surfaces.

4.3 Adjustable locating modules for locating of parts of the shaft type

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 [31], 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. This module allows locating of the workpieces with the diameter Ø25…100 mm and the length 100…500 mm, herewith the setup time makes 20…30 sec. depending on the diameter of workpiece, which should be installed. The accuracy of adjustment depends on the size of gap in the gearing, which regulates an angle between the supporting disks. Since the machining on the proposed fixture is carried out according to the quality classes 9–10 of accuracy, so the accuracy of adjustment should be higher the tolerance level on the machined surface. Thereof, it is proposed to produce elements of the gearing according to the quality class 5 that ensures the gap in the gearing up to 50…100 μm.

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.

4.4 Adjustable locating modules for locating of complex parts

It is often appear a problem of parts machining, which have curvilinear locating surfaces or surfaces with significant deviation from flatness. As an example are the suspension levers, rotation cams, steering rods or cams of crank-and-rod mechanisms. The qualitative machining of the parts of this type requires the producing of dedicated fixtures, that is economically inefficient for the wide range of nomenclature and standard

sizes of parts. So, the locating module [32], which is installed as a changeable unit on the machine vise, is proposed for locating and clamping of workpieces with curvilinear surfaces. The self-adjusting movable supports, which ensure locating on the curvilinear surfaces of workpiece with the simultaneous clamping is the special feature of the changeable unit. Use of the proposed changeable unit allows simplifying the locating of workpieces, increasing reliability of their clamping and the accuracy of the machining. It allows locating of workpieces with the overall dimensions in terms of 40x80 … 100x200 mm with the maximum deviation from flatness to 20 mm and weight up to 10 kg. The accuracy of adjustment makes 0.5 mm, that is determined experimentally, and it differs for different standard sizes of changeable units. Setup time while moving from one to another standard size makes 10…30 sec.

The adjustable locating-and-clamping module [33] is used for locating and clamping of parts, which have flat supporting surface and curvilinear shape (for example cams). The special feature of the proposed module is the self-adjusting movable supports, which ensure the possibility of locating on the lateral curvilinear surfaces of workpiece with the simultaneous clamping. The advantage of the manufacturing application of this module is the expansion of the technological features during the machining of parts with curvilinear surfaces. Dimensions of the locating workpieces could change depending on the standard size of fixture and the sizes of working table of machine tool and make 30x20x10 … 55x55x40 mm. Adjustment time is determined by means of manual or mechanical type of drive of clamping eccentrics and adjusting screws and makes 10…30 sec. The accuracy of adjustment is determined experimentally on the prototype in the production conditions.

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 numbers of setups. It is designed the adjustable locating-and-clamping module [34] for locating of lever-type parts, which allows carrying out the machining of part on the 5-axis machine tool per one setup and performing the adjustment within the range of sizes lxbxh = 112x40x26…180x64x42 mm. However, for locating of parts with other overall dimensions that are not within the indicated range the standard sizes of module could be change.

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 in order to reduce the setup time and reset time. It allows decreasing time from 30…45 sec. until 5…10 sec. The accuracy of adjustment makes 0.5 mm, that's reasonable explained by the error of adjustment. 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.

4.5 Adjustable clamping modules

For reducing consumption of the auxiliary time during the realization of the function of clamping on the drilling-milling-boring machine tools, that is the complicated task in mostly cases during use of the standard mechanized or manual clamping fixtures, is proposed to use separate mechanized or automated clamping units [35], [36].

Clamping of workpiece with module [35] is carried out by means of issuing the command by the CNC system of the machine tool to the stepped drives, which drive the clamping elements. After performed touching of the clamping element to the workpiece the stepped drive ensures clamping in the required position. Unclamping of the part is carried out in the same way, herewith during the step-by-step movement ahead of the catcher in the clamping module it simultaneously rotates in the position of unclamping, ensuring the free removal of the machined part. Clamping module [36] allows simultaneous locating of the prismatic parts in the "quadrantal angle" and their clamping.

The proposed clamping modules allow locating of workpieces with the height of 140…260 mm within the setup time 5…10 sec. and maximum clamping force 2000 N. Clamping modules are performed as an independent assembly unit, allowing their positioning at any place of the working table of the machine tool according to the form and dimensions of the workpiece. The use of the proposed clamping modules allow simplifying or eliminating the manual labor, decreasing the auxiliary time, and increasing the reliability of the clamping of workpieces on the CNC machine tools.

4.6 Efficiency of the proposed decisions

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 researches confirmed the sufficient accuracy of the adjustment mechanisms of the locating-and-clamping element 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 tool. 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], [38] and parts of lever-type parts [39] 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.

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, in particular: 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 also 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.

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