Information Support of the Computer-aided Fixture Design System

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Abstract. The article contains the rationale for the development of the computer-aided fixture design system (CAFD). The place of the CAFD among other automated systems is considered and the data flows are found between them. The structure of the CAFD system is suggested, which is distinguished by the module of optimization and allows to select the optimal fixture for the given production conditions. The purpose and place of each module in the structure of the CAFD system is grounded. The database of the CAFD system is a collection of libraries connected by logical connections. The database includes 15 libraries of engineering and design, general engineering, regulatory, reference, and optimization and calculation character. The classifications for the supporting, locating and clamping elements, locating charts and the clamping charts of the workpieces are developed.

Keywords: Computer-aided fixture design, production planning, optimal fixture, module of database management
KeyTerms: Development, SoftwareEngineeringProcess, Integration

1 Introduction

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. Over the past 15 years the product range has increased more than 2 times, constantly increasing their complexity, the demands for the accuracy and product quality are increasing [1,2]. Today's market requires more varieties of products, and consequently the equipment and processes should be more flexible to meet the needs of the market and reduce the amount of time to appear on the market. This necessitates the development and implementation of the innovative production solutions for the implementation of the processes which should be aimed at the intensification and automation of production. Integrated CAD / CAE / CAPP / CAM technologies provide a solution to problems of design, analysis and optimization, development of the technology of manufacturing products, production process automation and inspection. This can increase the productivity and quality of the developed production solutions.

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One of the promising areas of the intensification of the manufacturing production planning is the development and implementation of the computer-aided fixture design (CAFD) technologies which allow, in the automatic mode, to design fixtures, evaluate their effectiveness and develop the necessary design and production documentation. These systems can be integrated with CAD / CAE / CAPP / CAM systems, and thus perform a full cycle of design, analysis, synthesis and manufacture of fixtures.
Fixtures are an integral part of a closed loop technological system "machine tool – fixture – workpiece – cutting tool" and are designed for accurate locating and reliable clamping of the workpieces during the machining on the metal-cutting machine tools.
Fixtures affect the production of the competitive manufacturing engineering products, as evidenced by the following data: fixtures constitute 70–80% of the total tooling [3]; the proportion of fixtures is 10–20% of the total manufacturing system cost [4]; 80–90% of the time required for the production planning correspond to the design and manufacturing of fixtures [3]; 40% of rejected parts are due to dimensioning errors that are attributed to poor fixture design [5]; 70% of the new fixtures are a modification of the existing [6].
In today's manufacturing engineering, which is characterized by the instability of the range and volume of manufacturing capacity, a rational choice of the fixtures is actual, which put forward the following demands: flexibility, sufficient for machining of the parts within the machine tool specification; assurance of the specified accuracy of the machining; mechanized or automated changeovers when switching to a machining of the parts of different size; high stiffness of the parts and assembly units, which can take considerable cutting forces and ensure maximum use of the equipment power; tool availability to handle the maximum number of surfaces in one setup; high unification of the parts and assembly units, providing cost reduction of fixtures; high functional and production reliability of a fixture and its elements; economy [7]. The basic requirements for the creation of the fixtures are reduced to six groups, including the physical requirements, tolerance, constraining requirements, affordability, collision prevention, usability [8].
Therefore the main objective of this article is to present the conceptual structure of the CAFD system and to develop the information support for the entire fixture design process including analysis, synthesis, optimization, and verification procedures in order to ensure the effectiveness of production planning.

2 Related Work

Today people have many years of experience of developing and implementing of the CAFD systems which considerably accelerated and improved the process of fixture design, allowing the designers, at the design stage, comprehensively analyze the properties of the future fixture before its manufacture.
According to their purpose the CAFD are divided into systems designed for dedicated [9], modular [6], [10,11], and adjustable fixtures [9], [12]. CAFD systems for dedicated fixtures are meant for detail design of all fixture functional elements with the following assembling to meet the requirements of the specific sizes of the

workpieces. CAFD systems for modular fixtures are meant for fixture design process by means of assembling of fixtures from the set of prefabricated functional elements. The use of adjustable fixtures supposes locating and clamping the workpieces in specific range of sizes. Therefore such CAFD systems provide manufacturing engineers with design and assembly tools for fixture design from original and standardized fixture elements. A thorough review of the existing CAT and CAFD systems is considered in works [4], [8,9], [13,14,15,16].

According to the level of automation the CAFD systems are traditionally classified into interactive (I-CAFD), semi-automated (Semi-AFD), and automated (AFCD) [12]. The analysis of the existing CAFD systems showed that the typical structure [16] consists of four modules which provide a step-by-step solution of setup planning, fixture planning, fixture unit design, and verification of the fixture (Fig. 1). Verification is the essential stage in fixture design allows evaluation the designed fixture to draft proposal and production conditions.

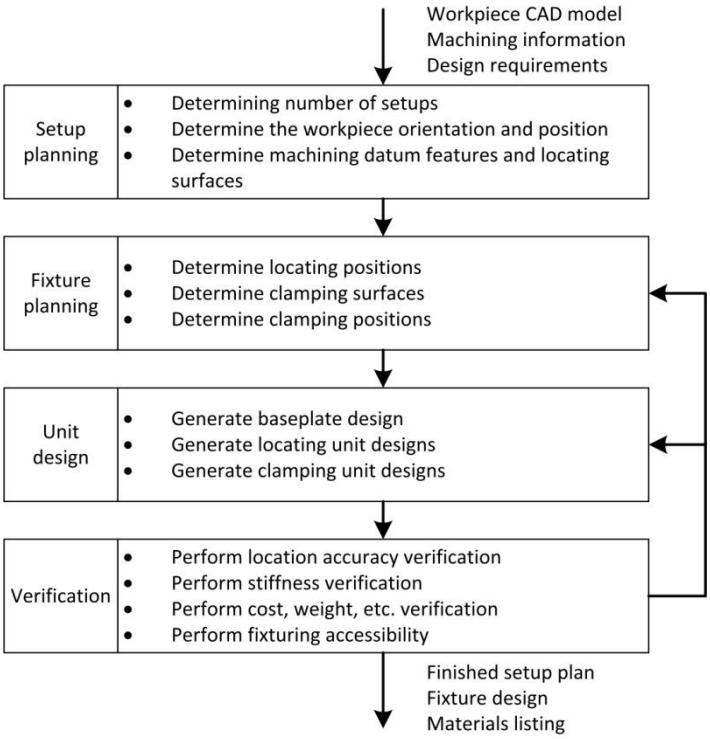

Fig. 1. The typical structure of the CAFD system (adapted from [16])

Today there is the problem of choosing the optimal fixtures. A variety of fixtures which are used for the machining of similar parts, on the one hand, provides many variants, on the other – significantly complicates the task of determining the optimal fixture for specific production conditions. Existing CAFD systems doesn't allow the execution of optimization procedures according to production conditions.

Taking into account that the fixtures are complex technical systems that differ according to different parameters (accuracy, flexibility, cost, reliability, performance, steel intensity, etc.) the effective choice of the best among the set of competitive variants is advisable to carry out by means of multicriteria optimization. Considering the complexity of the analysis and calculation of all the parameters necessary for the design of the fixtures, it is advisable to automate the process.

3 The Structure of the CAFD

3.1 The Place of the CAFD Among Other Automated systems

CAFD is one of the elements of computer integrated manufacturing, along with CAD / CAE / CAPP / CAM systems. This approach allows you to implement the fixture life cycle from design to its manufacturing, actualizing the geometric modeling and engineering analysis, process planning and automation of the manufacturing. The analysis of the data flows (Fig. 2) confirms that the CAFD structure must be built taking into account the integration of these systems.

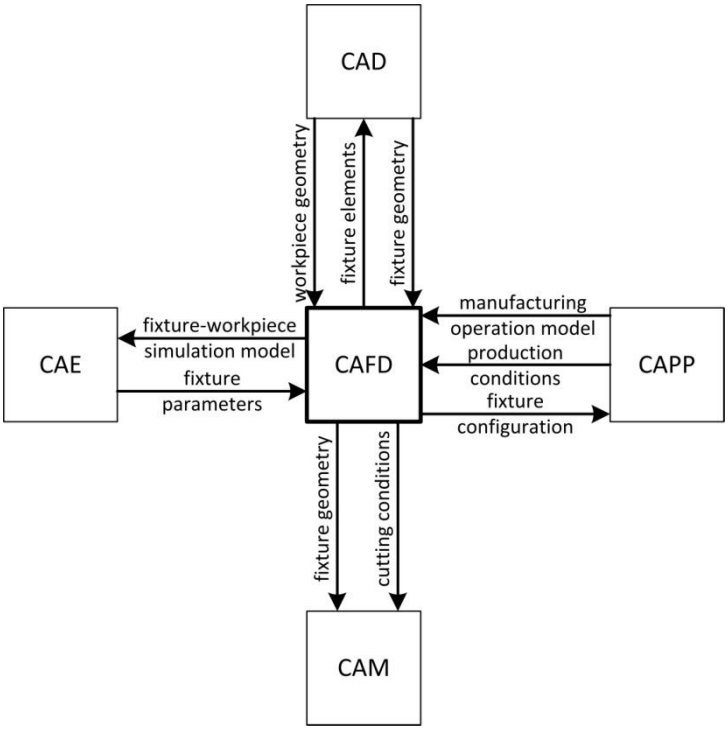

Fig. 2. The place of the CAFD among other automated systems

3.2 CAFD Structure

3.2.1 General Information

The suggested structure of CAFD system (Fig. 3) is the five modules that operate according to the developed algorithm in stages. The information support of the designing stages is provided by the database. The implementation of the mathematical models of all the necessary calculations is performed in the CAFD working modules which include module of the database management. The provision of the visualization of the results of the CAFD design involves integration with the three-dimensional solid design package Autodesk Inventor that allows working with solid state 3D models of functional elements of the fixtures which are contained in the relevant libraries.

3.2.2 Module of Input Data

Input data when designing are: the design parameters of a workpiece (geometry, overall dimensions, weight, material, workpiece stiffness, etc.); technological parameters (type of manufacturing operation, metal-cutting equipment, cutting tools, etc.); manufacturing parameters (type of manufacturing, batch size, etc.); other factors (economic, ergonomic, aesthetic, etc.).

3.2.3 Module of the Manufacturing Analysis of the Workpiece

The analysis of a 3D model allows determining the functional surfaces of the workpiece, which can be: work; locating; clamping. The work surfaces (one or more) – are surfaces that require machining on a given manufacturing operation. Locating surfaces (usually a combination of surfaces) – are surfaces that determine the position of the workpiece in three-dimensional space, constraining the workpiece a certain number of degrees of freedom (maximum six – three movements, three rotations). The clamping surfaces (one or more) – are designed for applying certain clamping force to ensure the permanent position of the workpiece during the process of forming surfaces.

The analysis of the above mentioned surfaces allows to determine from 3D model of the part: geometry (shape) of the surfaces; spatial relationship of the surfaces relatively to other surfaces; dimensional characteristics of the surfaces (length, width, height, diameter). From the drawing (or other accompanying documentation) it is necessary to get information: tolerance range for each of the surfaces; surface roughness; material; hardness of the workpiece material; type of heat treatment; other technical requirements.

Having information about the machining surfaces, the plan of the machining is formed. At this stage we distinguish: a schematic diagram of the surfaces machining; cutting conditions (cutting depth, feed, cutting speed); cutting force; required power of the machine tool.

The set of locating surfaces implement a theoretical locating chart with the definition of the points of contact of the workpiece with the locating elements of the fixtures.

The analysis of surfaces for clamps allows to select one of the typical clamping chart, as well as the points of contact of the workpiece with the clamping elements.

Based on the plan of machining, locating and clamping charts of the workpiece the setup and machining plan is formed, indicating the values and the direction of the cutting and clamping forces in a particular coordinate system.

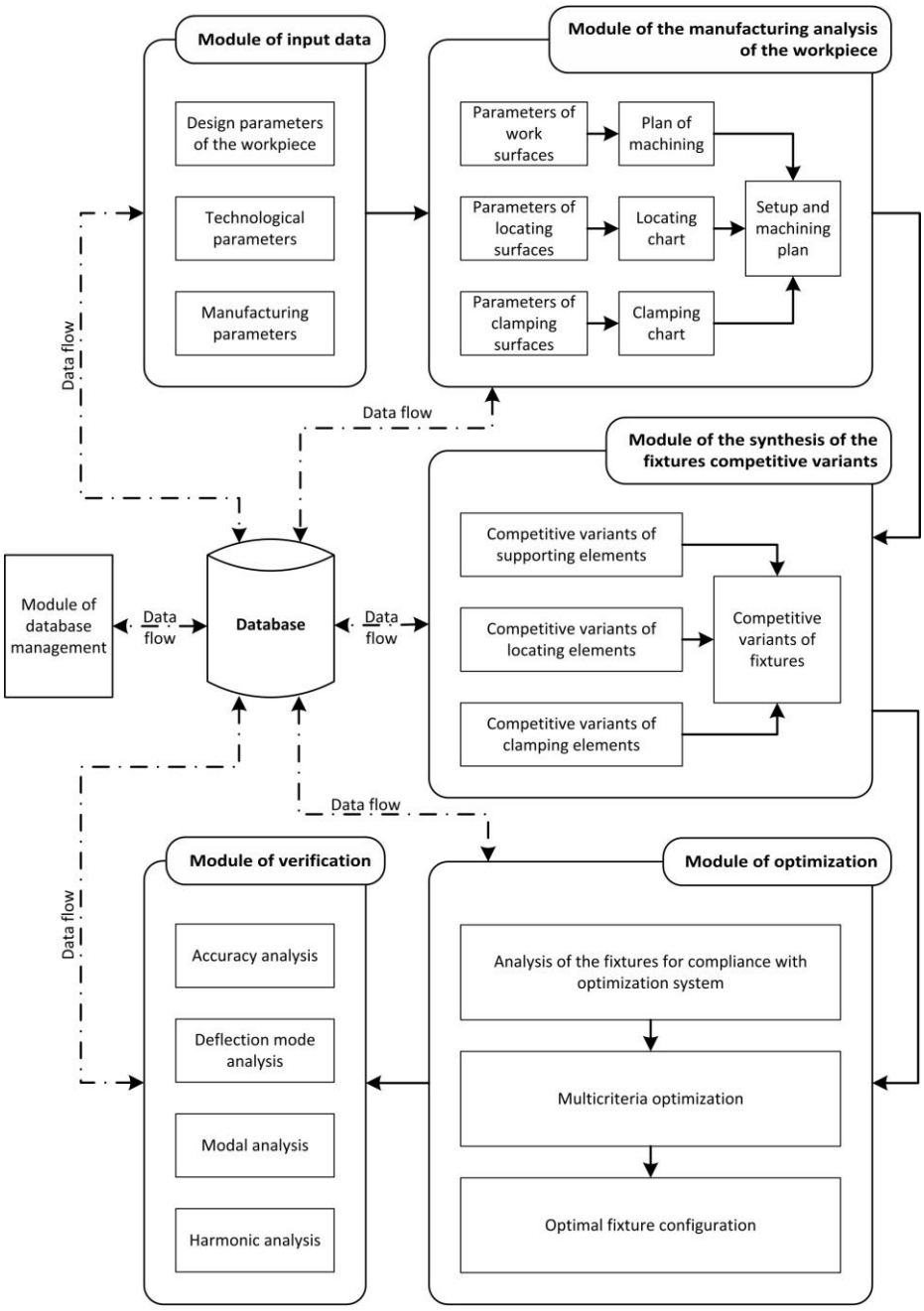

Fig. 3. The proposed CAFD system structure

3.2.4 Module of the Synthesis of the Fixtures Competitive Vatiants of the Fixtures

Based on the developed rules, including the selected locating chart and a clamping chart of the workpiece the locating and clamping elements are selected which correspond to the specified parameters. According to the overall dimensions of the workpiece, the selected locating and clamping charts the choice of the supporting elements is carried out. This allows to form a set of competing options of the supporting, locating and clamping elements. Then on their basis and taking into account the previously created fixtures contained in the library of the fixtures, the competitive variants of the fixtures are formed according to the developed algorithm [17].

3.2.5 Module of Optimization

The implementation of the module of optimization allows to choose the optimal fixture for the specific manufacturing conditions on the basis of the multicriteria optimization. The first step in this module is the choice of the fixtures that satisfy the system of technical constraints, based on a mathematical model and also reference data. For the fixtures that remained due to the imposition of technical constraints, the calculation of the parameters according to each criterion of optimality is performed. Then a multicriteria optimization according to the method of successive concessions is carried out [18]. As a result of the optimization an optimal fixture is found with identified criteria evaluations.

3.2.6 Module of Verification

The engineering analysis is a very important step because it allows you to control the basic parameters of the fixture. At this stage, the possibility to perform calculations on the accuracy of the workpiece machining, the research of the system "fixture – workpiece" on the deflected mode analysis, modal analysis, harmonic analysis is provided.

3.2.7 Output Data

The results of the CAFD system are: 3D-model of the fixture and specification of the elements, that are part of it; the list of the optimality criteria and calculated criteria evaluations for the selected fixture; the results of the engineering calculations; the information about the conditions of production.

4 Database

4.1 General Information

An important condition for the effective functioning of any CAFD system is the database that provides information support of the design process of the fixture, the accumulation and the storage of reference, design and technological and methodological information. The developed database is a collection of individual libraries-tables, in which the information necessary for the performance of the design is systematized according to the purpose. The detail of a conceptual database scheme is shown in Fig. 4. Between the respective tables and CAFD modules of the fixture the connections are identified (Fig. 5) that implements data flows which ensure the design process.

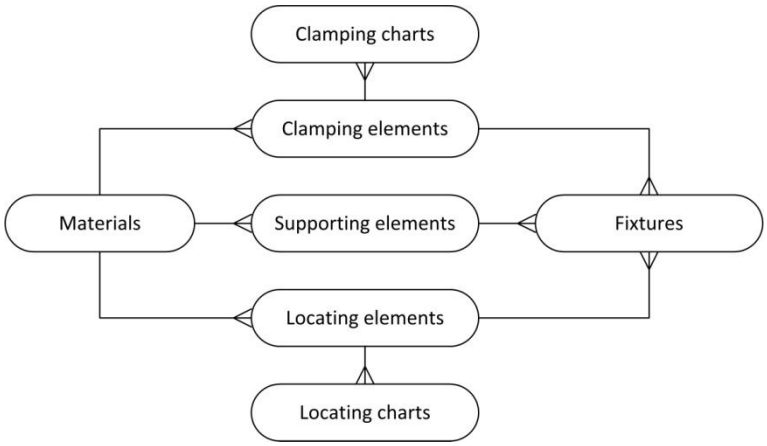

Fig. 4. Conceptual scheme of the data presentation (fragment)

4.2 Libraries

In general, the system provides 15 libraries used for full information support of the design process of the fixture (Fig. 5).

The library of the design parameters of the parts contains information about structural elements of the parts, their variety, standard sizes and so on.

The library of the technological information includes the list of data about the types of workpieces and the rational conditions of their use, types of the heat treatment and the typical processes of its implementation, methods of machining, classification of the manufacturing operations and steps, the typical structures of the manufacturing operations, the recommended parameters of the size accuracy and the quality of the surfaces.

The library of the manufacturing parameters of the machining contains information about the type of manufacturing, manufacturing capacity, batch size, level of flexibility, and the level of machining efficiency.

The library of the metal-cutting equipment contains information about the equipment for the drilling-milling-boring manufacturing operations. All the elements of the given library are systematized according to various parameters: the level of automation; the type of the layout of a machine tool; manufacturing capabilities; workspace overall dimensions; the type and a set of a tool magazine; the frequency of the spindle rotation; the power of the force actuator and so on. The library contains information about 1075 machine tools of vertical and horizontal layouts of more than 30 world manufacturers.

The library of the cutting tools contains technical information and manufacturers' recommendations about the cutting mode for drills, core drills, reamers, boring heads, spotfacers, chamfer bits, taps and also face-milling, end-milling, keyway-milling, plain-milling and disk cutters that are used for drilling-milling-boring manufacturing operations.

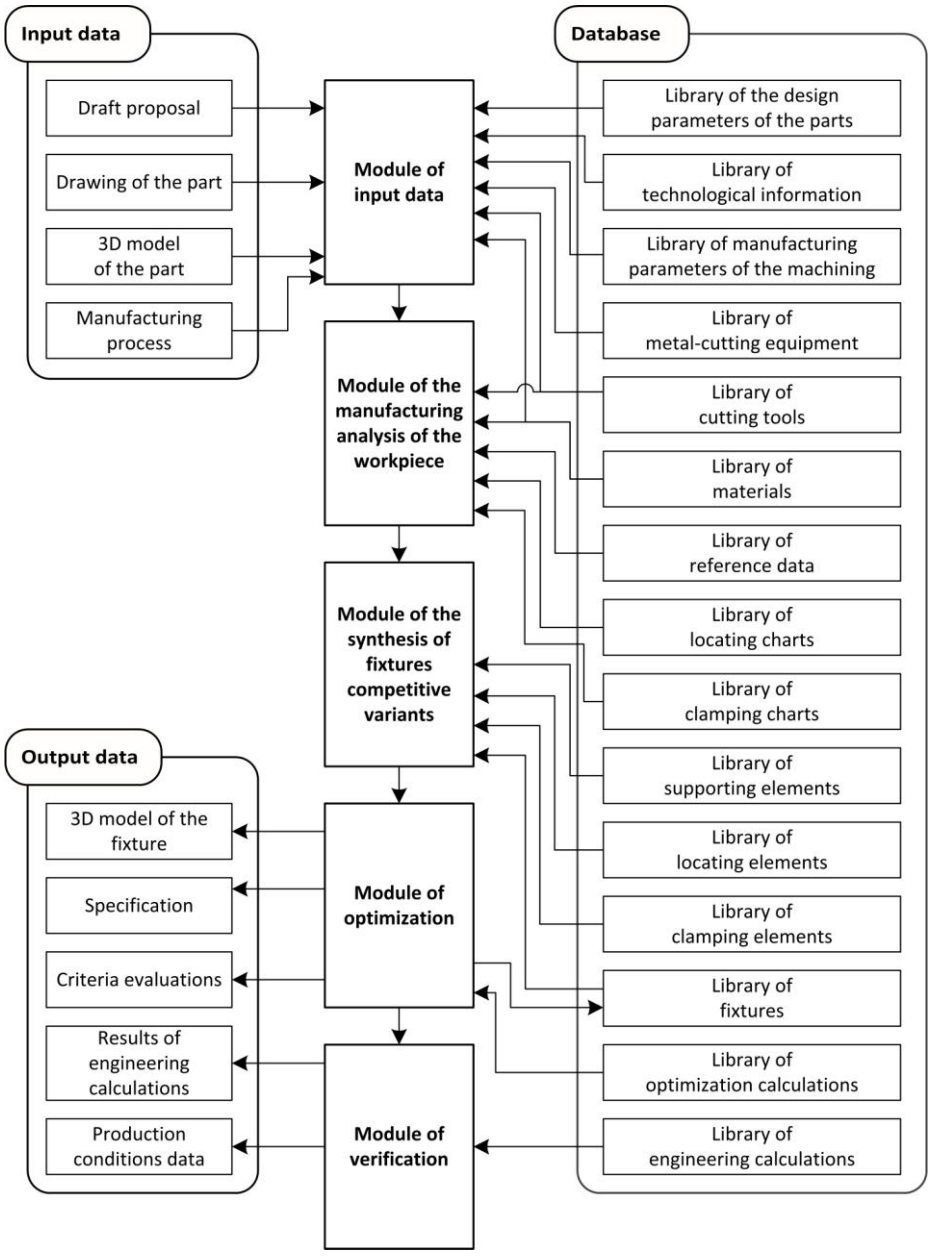

Fig. 5. The scheme of the interaction of the libraries of the database with the modules of the computer-aided fixtures design system

The library of the materials contains information about the physical, mechanical and technological properties, chemical composition of the manufacturable materials. In order to maximize the coverage of a large number of possible options for the produc-

tion of the machining workpieces, the library contains data on ferrous metals and alloys; nonferrous metals and alloys; non-metals.
The library of reference data includes information about tolerances and fits, quality class, tolerances of the form and position, processing errors, roughness of the surfaces, information on the cutting modes of the materials, standard time for machining of the surfaces, standard time for the fixture assembling.
The library of the locating charts of the workpieces contains classification of the typical locating charts (Fig. 6) of the prismatic parts, rotational parts (shafts, shaft-collars, flanges etc.), flat parts, and complex parts (levers, connecting rods, brackets, cantilevers, etc.). According to the library information it is possible to provide a defined locating of 90% of the workpieces that are machined on the machine tools of the drilling-milling-boring group.

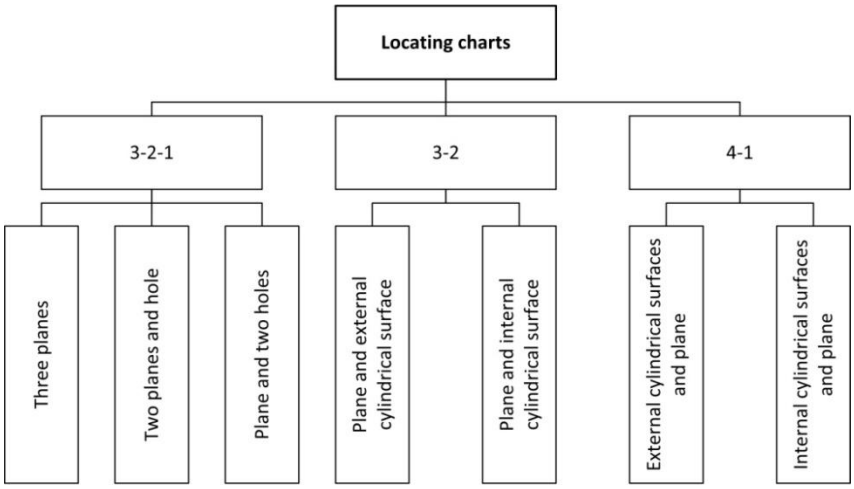

Fig. 6. Classification of the locating charts of the workpieces

The library of the clamping charts contains information about the most rational ways of workpieces clamping, based on the principles of the equilibrium position of the workpiece, and also take into account the sequence of the clamping of the workpieces in the charts with many clamping elements.
The library of the supporting elements includes a wide range of supporting elements (plates, cubes, angular plates, tombstones, etc.) that are the basis for creating of the fixtures.
The library of the locating elements contains a variety of locating elements (support plates, supports, V-blocks, locating pins), intended to implement theoretical locating charts.
The library of the clamping elements has a large selection of clamping elements (swing clamps, cam clamps, lever clamps, clamping straps, etc.) to ensure reliable clamping of the workpiece in the fixture during the cutting process.
The libraries of the supporting, locating and clamping elements provide basic technical characteristics of each element, including code, dimensions, mounting dimen-

sions, weight, material, size of the work surfaces, adjustment range, clamping force, etc., and links to related 3D models. Also the practical advice is given on the effective scope for different production conditions.

For the convenience of the identification of the functional elements in the proposed CAFD system a coding system is developed. These codes are unique for each elements. Such codes help the designer, looking only at the code, to make conclusions about the element. According to the developed classifier it is advisable to code all the functional elements with the help of the code from letters and numbers (Fig. 7), where the first letter indicates the purpose of the functional element (supporting – S; locating – L; clamping – C), the second sign – sort of the element, the third – type, the fourth – standard size (Fig. 8).

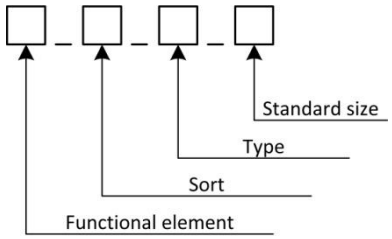

Fig. 7. Structural formula of the functional elements of the fixtures

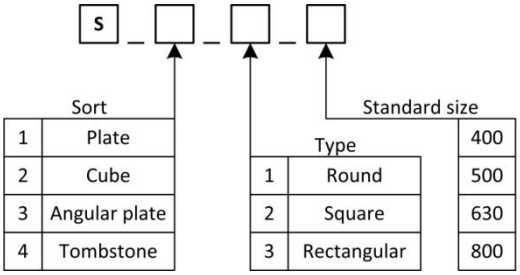

Fig. 8. Detailing of the structural formula according to the example of the supporting elements

The library of the fixtures is designed for the storage of the information about finished structural solutions which can be implemented with the help of the libraries of the supporting, locating and clamping elements for the typical parts of manufacturing engineering. In fact, the library is an archive of the finished project solutions obtained in CAFD before, with the definition of the object of machining, production conditions and technical specifications of the fixture.

The library of the optimization calculations is developed for the information support when choosing the optimal fixture for the given production conditions and provides a list of optimality criteria with the objective functions and technical constraints.

The library of engineering calculations contains information about reference data, calculation models, calculation templates that help to investigate the fixtures.

4.3 Working With the Libraries

The main functions of the developed database are the accumulation, updating, storage and provision of information to implement the design stages. A physical model of the proposed database is implemented with the help of the database management system MySQL. Working with database within the frames of the proposed CAFD is conducted both at the program level (provision with the information on the needs from the calculation modules), and at the level of user interface (editing data in the tables). The latter is implemented using a separate module of the database management, which is a part of the program complex of the CAFD system (Fig. 9).

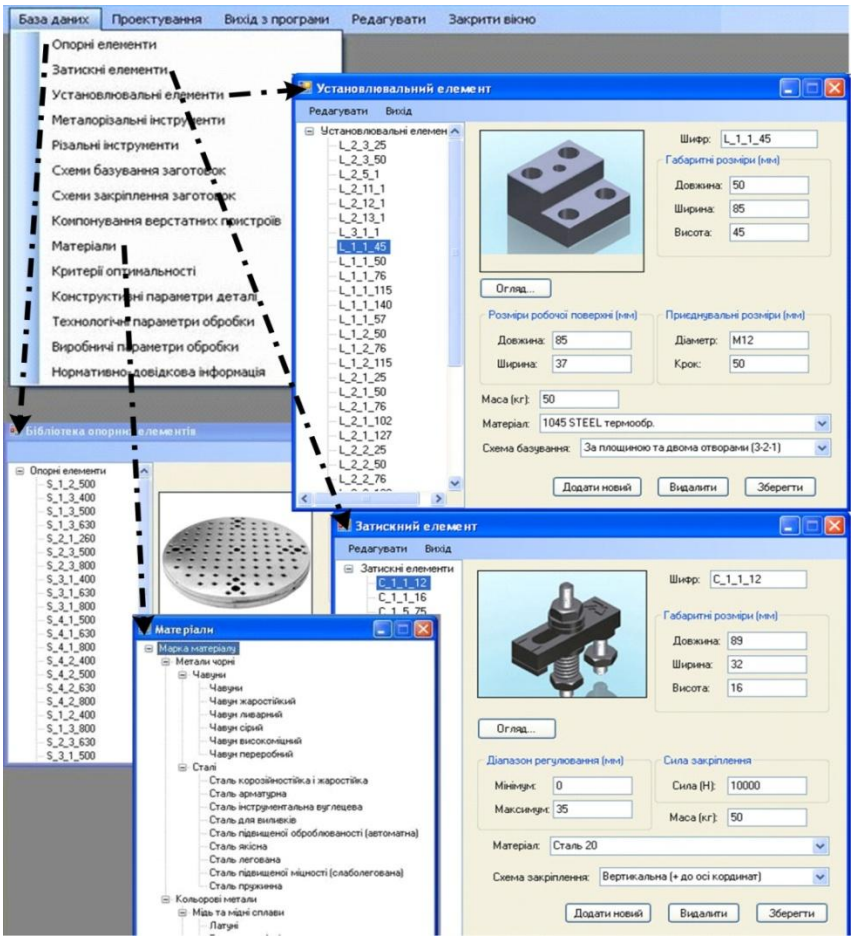

Fig. 9. The module of database management

The main module of the entire complex is made according to the MDI-interface technology that provides the ability to open several documents. The call of commands that allow the user to work with the information is through the main menu. The windows

for the work with the individual libraries are implemented in the form of the subordinated forms that are created within the container – the main form. The user interface provides access to the database online.
Each command of the submenu provides access to the screen forms, which provide the users of navigation means in the database, view and editing of the available information.
When designing the user interface of the screen forms of the control module of the database, standard components for Windows are used, that provides an intuitive interface.

5 Conclusions

According to the results of the study the necessity of developing CAFD with optimization procedures is grounded, the use of which will shorten the term for the production planning.
The structure of the developed CAFD includes not only conventional design stages, which are implemented as individual modules. The key difference of the proposed structure is the module of optimization, the implementation of which will generate the most advantageous variants for the fixtures.
The information support of the design process is performed by the developed database, the model of which covers the whole range of relevant information: of production, general engineering, regulatory, reference, and optimization and calculation character. According to the results of the analysis the connections of the calculation modules are established with the tables of the database.
The further work is directed to replenish the information storage of the databases, rank and improve data flows and logical relationships between them in the functioning of CAFD, the development of algorithms and methods of the automated synthesis of the fixtures and their multicriteria optimization that would ensure effective interaction with the computer-aided systems of the design and production orientation.

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