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ALGORITHM FOR AUTOMATED MODELING OF A MACHINE VISE

Dimka VASILEVA, Mariya KONSULOVA – BAKALOVA, Iva STOYANOVA

Abstract: *Due to the variety of different types of technological equipment, each of which has multiple configurations, the modeling of a fixture is time – consuming and expensive, because they do not appear in the standard libraries of modeling software. The type of fixture that is under consideration is a machine vise. The main goal is to create an algorithm for automated modeling of it, in a CAD area. The algorithm is developed for the use of engineers to quickly update and expand their digital libraries, as well as to timely adjust the generated models to the assemblies. After that the models can be used in systems, where predicting failure of manufacturing is minimizing cost and time of production.*
Key words: *Algorithm for 3D modeling; Automated 3D Modeling; Machine Vise; Computer Aided Design*

1. INTRODUCTION

When prismatic workpieces are machined by milling machine they must be correctly oriented, relative to the trajectory of the working movement of cutting tool, so that the corresponding surface can be formed. Technological equipment like fixtures and machine vises are used for orientation and holding workpieces during manufacturing operations. As a result, the accuracy of machine processing and productivity are increased by them. Also, they expand the capabilities of milling machines. Technological innovations are advanced enough to allow them to be implemented in already digitalized world, that we find ourselves in. Rapid and accurate creation of virtual analogues of real machines and technological equipment, requires significant effort, time, and high qualifications of designers. So, it is necessary to make this modeling process more effective and efficient by automating it.

Manual 2D and 3D modeling [1, 2, 3] are the most common methods for digital modeling of a machine vise. Therefore, it takes a lot of time and effort to create the desired model. It has been established in [4], that it would be more efficient to develop one design strategy for each type of fixture, than to attempt to develop a general strategy for all types of fixtures. For this purpose, in some cases like in [5], structural fixtures elements are used to create a functional design solution. The connection of these elements with functional requirements and typical fixture components are defined via tables and rules mapping. To achieve this in [3] a methodology is developed, to simplify this task by determining fixture components and assembly sequences, in a 3D – modelling environment. A fixture elements database is established where they are divided into different categories, depending on their geometries and functions.

Another method to speed up the modeling process of a technological equipment is in [6], where its done by Visual Basic for Applications (VBA) and macro code within SolidWorks software. To achieve this, it is essential that the design module to perform a selection of required fixture components, based on a set of predefined production rules [7]. It is shown in [8], that two main tasks remain: First, there is a need to provide more summarized fixture design method. Secondly, a greater focus is required on supporting detailed design of a fixture's physical structure. All of these methods and automated modeling tools focus on fixture assemblies, that are configurable and built by multiple elements. But it is not specifically mentioned that they can be implemented in automated modeling of a machine vise.

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The vise has many advantages, as well as being available in different size and shapes, ranging from cheap and simple structure, to very expensive and complicated devices [1]. As a result of its use in manufacturing engineering production, the accuracy of processing and productivity are increased. A main disadvantage of this type of technological equipment, is the duration of time that is required, in selecting an appropriate machine vise and to integrate it into the digital and real area. The correct choice is determined mainly by type, dimensions and material of the workpiece.

To reduce this disadvantage, the article focuses on the accelerated creation of a 3D model of a machine vise and its elements. This is done by creating an algorithm for automated modeling of it. Which in turn helps the fast digital creation and integration of each of its elements and their configurations, in library database. This helps automating the selection and digital modeling of appropriate machine vise, which significantly enhances productivity in mechanical engineering.

2. STRUCTURAL ELEMENTS OF A MACHINE VISE

Before starting the process of automated modeling of a machine vise, it is necessary to know all of its structural elements and their characteristics. Through this approach they can be grouped by functionality, specific characteristic and other criteria. The aim is to achieve their accurate modeling in digital area, by establishing mechanical relationships between them.

The type of machine vise that is under consideration has a fixed body, one movable jaw, and a screw clamping mechanism, which is manually operated – Fig.1. This is the most common type that is used for fixturing workpieces in manufacturing, using CNC (Computer numerical control) milling machine. It is constructed by the following main structural elements:

- Body – 1;
- Additional body – 2 and 3;
- Jaw plates – 4 and 5;
- Screw mechanism – 6 and 7;
- Bolts – 8 and 9.

The assembly of additional body 2, with jaw plate 5, is carried out by bolts 9, as they form the movable jaw of the device. To an additional body 3, a jaw plate 4 is attached, by bolts 8, as they form the fixed jaw. These two types of jaws are structural elements of a machine vise. They are needed for the purpose of tightening the processed parts and workpiece, in the working area of CNC milling machines.

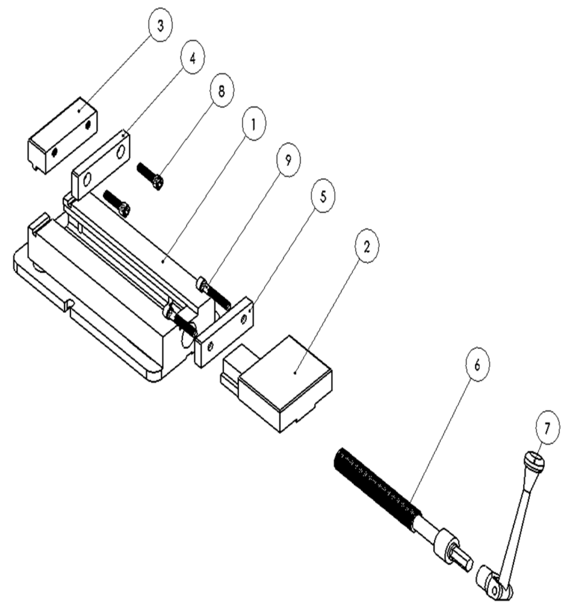

Fig. 1. Structural elements of a machine vise.

For minimizing the auxiliary machining time, a machine vise must allow easy and quick orientation of the workpiece in it, as well as its placement on the machine.

The shape and overall dimensions of body (1) depends on configurations and dimensions of the workpieces. The basic working dimensions of fixture machine vise determines maximum allowable dimensions of the workpieces, that it can handle. These basic dimensional parameters are entered into a table database (Tab.1), from which various dimensional configurations of the fixture can be determined.

For this type of machine vises only one of the additional bodies is movable (2), the other is fixed (3). Because of that, having a fixed body is needed for a stable support surface that can bear the weight of the part and its force applied to it without bending, shifting, or breaking. Jaw plates (4 and 5) are installed on the additional bodies. For that purpose, they must be durable enough to withstand forces of friction, pressure and machine cutting but also should not deform workpieces.

Table 1

Basic parameters for automated machine vise modeling

№	Width - W[mm]	Height - H[mm]	Thickness - T[mm]	Jaw Opening - O[mm]
1	60	31	12	232
2	100	30	15	90
3	102	38	18	100
4	102	63	15	125
5	102	79	17	130
6	126	98	18	148
7	126	120	21	153

Jaw plates are most often parallelepipeds with an important requirement being their opposite sides to be parallel and those that touch each other to be perpendicular. A study was made, focused on basic dimensions of the elements of machine vises, from various manufacturers. Based on this analysis, main dimensions of existing types of machine vises and jaw plates are derived (Tab.2).

As a result, it was determined that the variety of jaw plate size combinations is large. In addition to their dimensions and type of material, they can also be classified by the profile of their working surface:

- Plane jaw plate;
- Serrated jaw plate;
- Prismatic jaw plate;
- Step jaw plate;
- Grip jaw plate;
- Extra – high jaw plate;
- Pull – down jaw plate;
- Etc.

The handle (7) can often be replaced by a simple L – shaped wrench or spanner. It is attached to main screw (6) to create a screw mechanism. The function of this handle is to provide rotational movement of the screw of the machine vise, when used by machine operator. This occurs at the stages when tightening and loosening of workpiece is required.

When basic features needed to build the bodies of the structural elements are analyzed, they should be modeled using a 3D software. In this way, a complete digital copy (3D model) of the machine vise can be created step by step. The advantage is that all structural elements of it are exchangeable and replaceable. Thus changing them if it is necessary, does not compromise the accuracy of fixing.

Table 2

Basic parameters for automated jaw plate modeling

№	Width - W [mm]	Height - H [mm]	Thickness - T [mm]
1	55	15	10
2	60	31	12
3	64	20	12
4	80	15	10
5	80	39	16
6	90	25	14
7	100	20	12
8	100	30	15
9	100	40	18
10	102	34	40
11	102	35	15
12	102	38	18
13	102	44	25
14	102	63	15
15	102	79	17
16	113	32	12
17	113	40	15
18	113	40	12
19	125	40	12
20	126	98	18
21	126	120	21
22	150	25	14
23	151	40	18
24	151	45	18
25	151	121	24
26	152	44	18
27	152	46	44
28	152	47	18
29	152	51	25
30	203	56	25
31	203	56	50
32	203	58	27
33	203	58	27

Based on the analysis and classification of the individual elements of this type of machine vise, necessary information was gathered to build a structured and well – organized database. In this way, digital models of the construction elements and their characteristics are easily found, quickly modeled and positioned precisely in a 3D area. This of course minimizes and reduces physical and monotonous human labor, which means increasing the level of production automation and reducing chances of errors occurring. Hence construction of various automated systems in mechanical engineering production such as digital twins, can be supported.

The rapid and accurate creation for virtual copies of CNC machine tools and technological equipment, requires significant effort and high qualification of designers. Bringing a certain degree of formalization into this process, supports generation of a large number of elements and assembled units of technological equipment, used in manufacturing production. This is achieved using 3D software and modules that provide automated design. The automation of digital modeling process of a machine vise is a reason for implementation of higher requirements for accuracy, safety and reliability during manufacturing of parts. This increases accuracy and quality of processing, prevents errors from occurring (which shortens correction time), reduces costs, and generally increases the efficiency of production process.

3. METHODS FOR DIGITAL MODELING

The digital modeling of a machine vise can be considered as a series of steps. The most common sequence, for construction of geometric model in CAD (Computer – aided design) systems, is summarized in the following steps [9]:

- Creating a geometric shape using 2D primitives;
- Adding interconnections and constraints;
- Dimensioning;
- Creating a 3D model;
- Repeating the previous steps, until the required model is achieved;
- Editing the model (if needed);
- Assigning material to the model;
- Creating technological documentation.

For optimizing this sequence of modeling, in modern CAD systems is used parametric modeling. This is a computer – based method, used for creating geometric and dimensional constrains. These connections between different parts of the model (2D and 3D), allow automated updating of the entire model, when one or several parameters are changed. In addition to values, formulas, and constrains various types of criteria can be set as parameters such as: dimensions of a 2D or 3D primitive to be greater than, less than or equal to a certain value or ratios such as maximum allowable stress values, that a surface can resist.

Once the parameters are settled, it is possible to be found that some of them obstruct the modeling of required digital form. This is due to relations that fix the location and connections between geometric objects (tangency, parallelism, concentricity and others) [10]. This is not a disadvantage, but rather a feature that should be paid attention to.

Model parametrization is used to define special parameters and dimensions of the model. It allows creation of flexible and easily adaptable 3D models. This is an opportunity for quick, easy, and automated construction of different variations of model’s shape and size. Another advantage of this type of parametrization is creation of libraries, containing necessary structural elements for the digital construction of a machine vise. With this the process of building digital objects, which are subsequently subjected to necessary simulations in safe digital environment, is accelerated. They can also be used to make a direct connection between them and the real object, of which they are a copy. As a result, they could support the construction of digital twin technology.

4. ANALYSIS OF EXISTING SOFTWARE FOR AUTOMATED MODELING OF MACHINE VISE

The creation of a summarized algorithm for automated modeling of machine vise, is largely related to selection of an appropriate program for automated modeling. Software application programs are used, allowing automated modeling of the construction of a machine vise and its simulation in digital area. Following are examples of some of the most commonly used computer programs, for creating 3D models in mechanical engineering.

CATIA is a typical representative of software for 3D modeling, design, and simulation. It is mainly used in mechanical engineering, as well as in other areas of industrial production [3]. It has libraries of standard fixture elements, already done models of technical equipment but no machine vise, nor its elements. CATIA can also be used to create custom libraries, but it has two main disadvantages: high price and a complex interface.

Ansys combines a multitude of built – in or external modules for design, modeling, and simulation. Its modeling area has available databases with libraries of already – made elements, but does not have a pre – built database with elements of a machine vise. Another major disadvantage of Ansys is high purchase price, therefore not all mechanical engineering companies have capital to purchase it.

PTC Creo Parametric allows parametric modeling and it is suitable for a variety of products, that are manufactured by teams of engineers. It has a large database of models, but they are not suitable for machine vise. Despite its advantages, the program has disadvantages such as high price, high requirements for the systems that support it, difficulty in learning, and others.

SolidWorks is middle class software, which makes it much more affordable for mechanical engineering companies to purchase. Has the same basic functions as the programs mentioned so far, but its working principle is much more intuitive and easier to learn. Some of them are built – in libraries of digital models, but it also allows new ones to be created in addition to them. The ability to operate with macros and programming languages, enables greater automation of the modeling process, compared to the standard working principle. These advantages make SolidWorks a software application suitable for automated modeling of machine vise [11, 12].

The leading CAD systems – CATIA, Ansys, PTC Creo Parametric, and SolidWorks were analyzed and it was found that despite offering wide variety of design and simulation capabilities, not all of the platforms are equipped with already made solutions or libraries for modeling machine vise. Nevertheless, SolidWorks was identified as the most accessible and adaptable tool for automated modeling thanks to its intuitive interface, ability to utilize macros and scripts, and expandable library structure. These features are regarded as key factors in making it the most appropriate choice, for development and implementation of an algorithm for automated modeling of a machine vise, in modern mechanical engineering. Development of such algorithm is seen as a significant contribution to improvement of efficiency, standardization, and digitalization of design activities in industrial practice.

5. INTEGRATED AND EXTERNAL MODULES FOR MODELING PROCESS AUTOMATION

Parametric CAD software is not a single piece of software but a set of integrated or external modules, each with its own advantages and limitations [13]. The most important requirement is their interconnection and compatibility requirement, between them and the main software they work with. The presence of even the smallest inconsistencies leads to unintentional errors in data, which results in additional costs and loss of time [14].

Integrated modules are represented by a specific dialog box or segment of a CAD software product. There, necessary information is specified for specific parametric modeling procedure. APM is CAD/CAE (CAE: Computer – aided engineering) software, where Graph is an integrated module to it. It is a graphical editor, that is used to facilitate design process [15, 16]. APM also has a module, of another variety, named the WinMachine parameterizer. It has a database with necessary theoretical and model information, connected to it. Also, a user defined database with necessary mechanical components can be created. They can subsequently be used to create related drawings or to be used in CAE simulations. It is optimal to create a personal archive, with the most frequently used models and data in relevant production. Some of the integrated modules in SolidWorks are designed for creating 3D model with a variety of configurations, based on manual parametric modeling. This is done managing the configurations of one part in a single file, which can lead to slow – loading visualizations. Also when assembly is created and one configuration of a part is changed with another, errors in relations, constrains and parameter conflict may occur between the assembly parts. Those disadvantages are time consuming, especially when the engineer doesn't have knowledge and experience in parametrization modeling.

External modules for automation of modeling process, must be easy to use and to interact with relevant CAD software. They most often work on the principle of creating a parametric model, which is done through specified variables and constraints. Besides being basic, they can also be auxiliary as input data for following commands. Another beneficial aspect of building these modules is that they allow an option, where a command is–active or inactive, for particular task. In [17], a special application is developed, where a design process is automated, only by entering input data. In [18], a library system was developed based on SolidWorks, which is composed of a database, a user interface, and a modeling module. Design data includes dimensions, constraints, and geometric relationships [19]. This lower the risk of design inconsistencies and errors, by making it accessible to engineers with variety of levels of experience. Because every task is done automatically. Due to its flexibility and ability to work with SolidWorks, the algorithm for automated modeling of a machine vise, is chosen to work through an external software module.

6. ALGORITHM FOR AUTOMATED MODELING OF A MACHINE VISE

In this case, to build an external module is necessary to create an algorithm of sequential steps, to be followed. The main aim of the algorithm for automated modeling of machine vise, is to provide an appropriate steps of activities [20]. Through which, selected type of machine vise can be automatically modeled. To achieve this goal, it is necessary to define input, output data, and rules.

Information and conditions are established in advance, through a detailed structural analysis of a machine vise, as well as its component elements. Based on this data and what characteristics and structures that a real object should have, it is possible to automatically create a 3D model of a real vise.

To achieve maximum identity between real machine vise and its digital copy, characteristics of the workpiece, that is clamped in it, must also be established. Many parameters of technological equipment depend on its shape, dimensions, material, and other characteristics. In this particular case, algorithm's operation is presented in SolidWorks.

Before the algorithm is started, it is fundamental to model the workpiece or to insert a previously created one. All other steps of the algorithm, for automated modeling of a machine vise, are represented in – Fig.2. They are done thanks to an already entered parameters and relationships, that sequentially create all necessary elements of the vise.

The automated modeling begins by creating the stationary jaw of a machine vise. It is positioned on the selected surface, when the algorithm is started. Correct positioning of the jaw relative to the workpiece, must be determined by a technological operation that is going to be performed on it. This is basic stage by which successful continuation of remaining steps of the algorithm, depends. If a surface is incorrectly chosen or if one is selected with an inappropriate position, it is mandatory to correct the action and select a surface that satisfies the specified criteria.

One of the criteria for using a specific vise model, is the overall dimensions of the workpiece. That is why automatic extraction of a workpiece geometry is performed. The correct

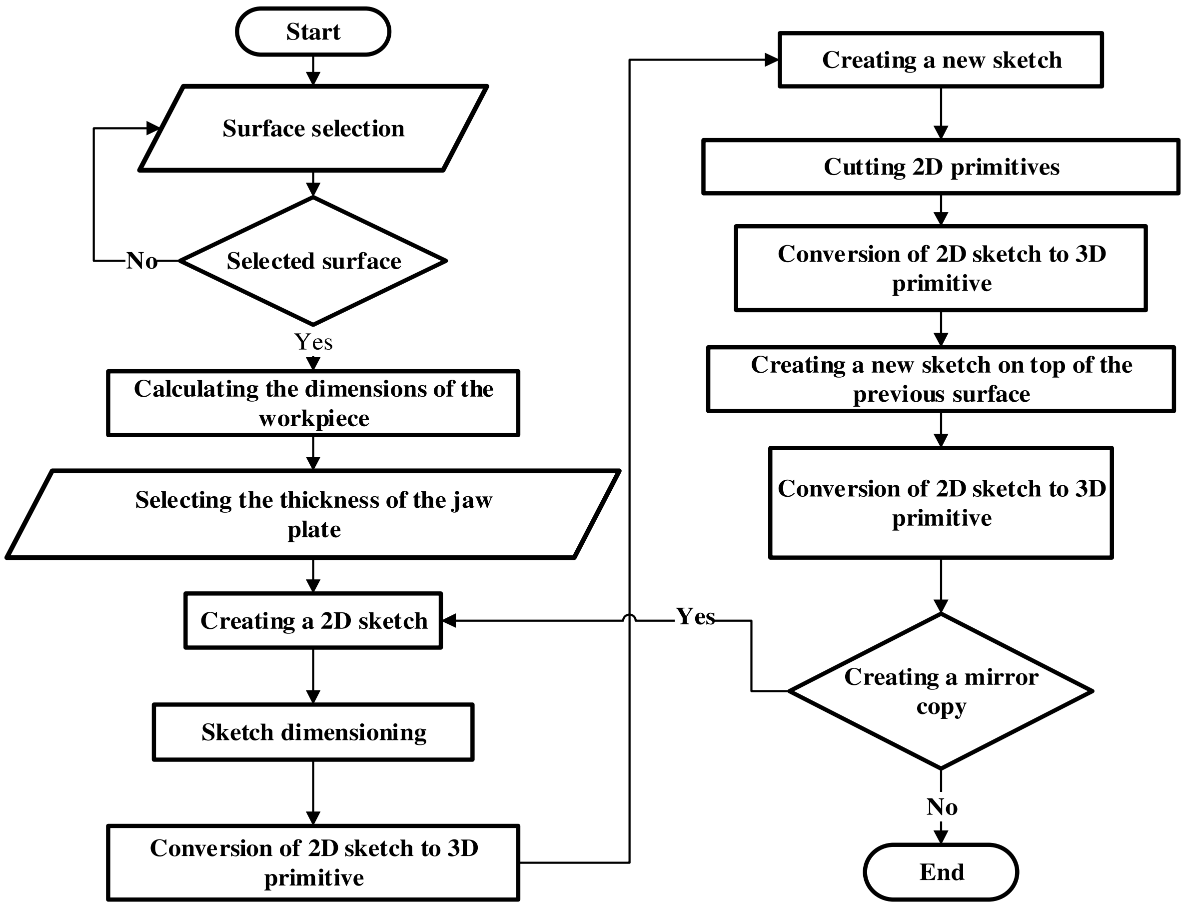

Fig. 2. Algorithm for automated modeling of a technological equipment - machine vise.

construction of the remaining elements of a machine vise, depends on this step. Because of that, the modeling process is completely automatic. It is done by standard commands in specific CAD system, creating 2D sketches, modeling new 3D geometry, forming holes, etc. It is planned that after the modeling of the fixed jaw is completed, a mirror copy is made to create the movable jaw.

On fig.3. are illustrated main steps for the algorithm of automated modeling, of a machine vise. First, a 3D model of the workpiece is created or integrated in the software (fig.3: – a). Then jaw plate is modeled on the workpiece (fig.3: b – f), where it is important to create a stepped hole. When the jaw is assembled with the additional body, it is important that the bolt heads must be coincident to the working surface of the jaw. Otherwise there will be a production error. Next comes the automated modeling of the additional fixed body (fig.3: g – h). Thirdly, the main body (fig.3: i – j). Finally, there is a step of automated creation for copying of the jaw plate, if it is necessary. Then the software repeats the entire process of automated modeling of the jaw plate, on the opposite surface of the workpiece (fig.3: k - i). Through these clearly defined steps and parametric dependencies, it is achieved fast 3D modeling of a machine vise. This increases efficiency and reliability of design, in this type of technological equipment.

The algorithm for automated modeling of a machine vise is a prerequisite for creation of an author's software module. This is done by API (Application Programming Interface) module, attached to SolidWorks. It makes possible communication between the program and external applications. External module is preferred, over macros running through Visual Basic, because C# programming language allows greater flexibility in programming. Following the next stage of improvement and expansion, databases will be capable of communicating with the relevant authoring software, that will be created. It will assist the selection of already modeled structural elements of a machine vise. In this way, the modeling process of this type of technological equipment will not only be automated but also optimized.

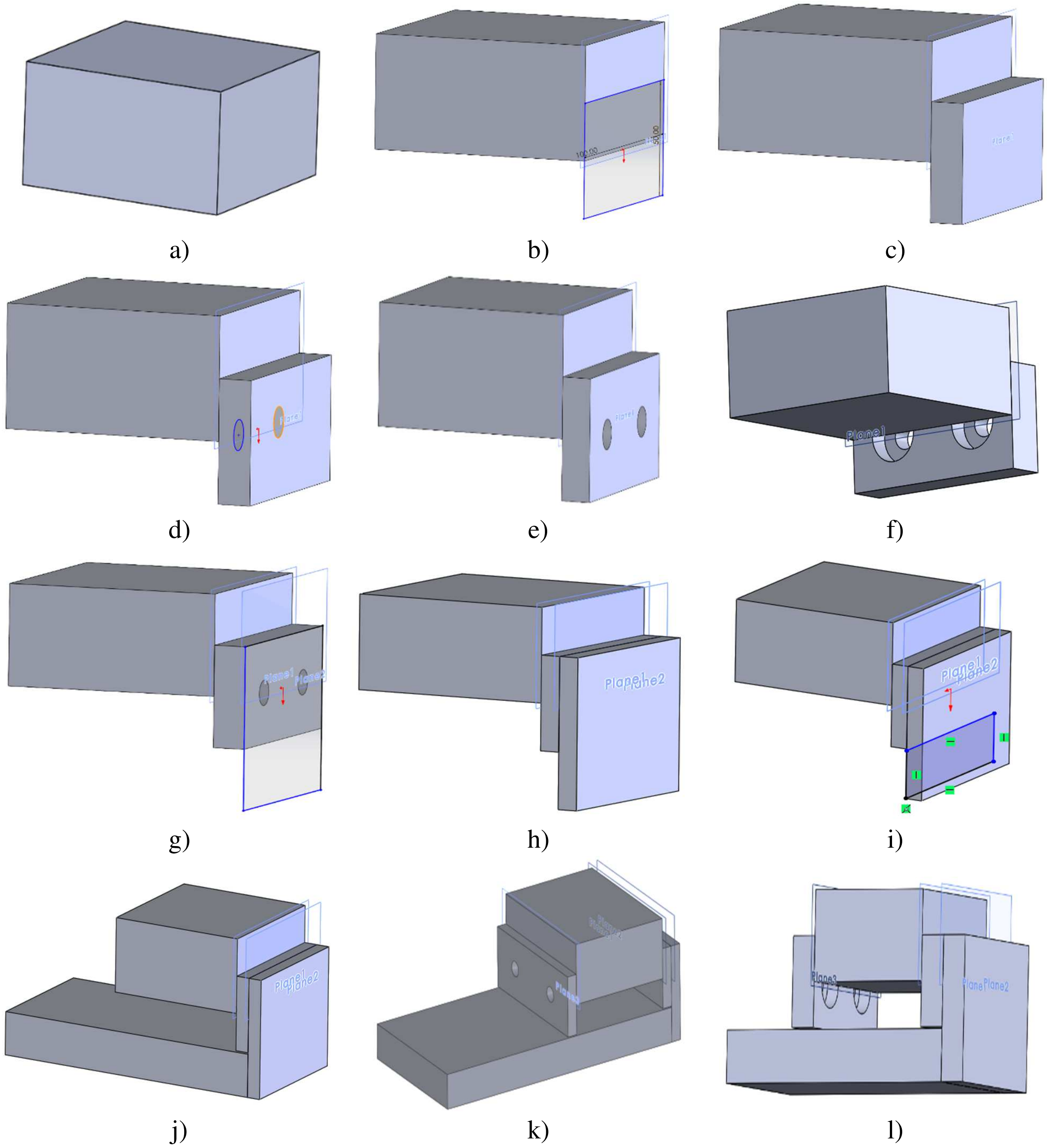

Fig. 3. Creation and dimensioning of 3D primitives for automated modeling of a machine vise.

7. CONCLUSION

This paper presents a research for creating of algorithm for automated modeling of a machine vise. It begins with an overview of structural elements of machine vise and current digital methods, that are available to create 3D model. Then there is an analysis of current CAD softwares, where are highlights of their capabilities and limitations. SolidWorks is chosen to be the most suitable for the purpose of creation a digital model of a machine vise. After that, differences between integrated and external modules of software are examined, emphasizing their potential in reducing manual intervention and increasing the efficiency of automation in digital design.

The proposed algorithm, for automated modeling of a machine vise describes the stages of automatically building a parametric CAD model, of a real machine vise. Automating the modeling of this technical equipment, can help the creation of a digital twin of a real machine vise. This not only speeds up modeling and design process, but also creates prerequisites for the integration of intelligent production systems, in accordance with the concepts of Industry 4.0.

Next stage of the research is creating a user interface for an external software module, that will work according to the presented algorithm for automated modeling of a machine vise. Also, based on the made classification, tables containing dimensions, and characteristics a library system of 3D models of its structural elements will be created. These advancements will significantly enhance the accessibility and efficiency of machine vise design and analysis, for implementing it in digital manufacturing systems. Those systems can monitor and control physical processes to detect and prevent errors during the production processes on CNC machines.

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Algoritm pentru modelarea automată a unei menghine de mașină

Rezumat: Datorită varietății diferitelor tipuri de echipamente tehnologice, fiecare dintre ele având mai multe configurații, modelarea unui dispozitiv este consumatoare de timp și costisitoare, deoarece acestea nu apar în bibliotecile standard ale software-ului de modelare. Tipul de dispozitiv care este luat în considerare este o menghină de mașină. Scopul principal este de a crea un algoritm pentru modelarea automată a acestuia, într-o zonă CAD. Algoritmul este dezvoltat pentru utilizarea inginerilor pentru a-și actualiza și extinde rapid bibliotecile digitale, precum și pentru a ajusta în timp util modelele generate la ansambluri. După aceea, modelele pot fi utilizate în sisteme, unde estimarea eșecului de producție reduce la minimum costul și timpul de producție.

Dimka VASILEVA, Assoc. Prof. PhD, Technical University of Varna, Manufacturing Technologies and Machine Tools, d.vasileva@tu-varna.bg, 052 383 357.

Maria KONSULOVA – BAKALOVA, Assoc. Prof. PhD, Technical University of Varna, Manufacturing Technologies and Machine Tools, mbakalova@tu-varna.bg, +359 52 383 208.

Iva STOYANOVA, Mag. Eng., PhD student, Technical University of Varna, Manufacturing Technologies and Machine Tools, iva.stoyanova@tu-varna.bg, +359 52 383 208.