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INTEGRATED CAE/CAD SYSTEM FOR PARAMETRIC DESIGN OF MECHANICAL ASSEMBLIES

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Abstract: *The correct and quick design of assemblies for execution and implementation in the industrial environment is one of the economic environment's goals. This paper presents a CAE/CAD system for designing an assembly, created with the help of a custom application (user interface). To facilitate the technical calculation report's creation, it was implemented into a spreadsheet program that takes information from the user interface. This serves both to keep the data in a digital format that is easily accessible and to modify the data and results in real-time, eliminating the need for repeated calculations. As a result, the designer saves time, as there is no need to redo the calculations when errors occur or when one of the parameters is modified.*

Key words: *CAE, CAD, Integrated system, User Interface, C#.*

1. INTRODUCTION

The use of dies in the sheet metal deformation process provide a precise and consistent framework for shaping and forming metal components. They are designed to ensure accurate positioning and alignment of the workpiece, resulting in uniformity and repeatability of the produced parts, therefore enabling efficient mass production of components. Also, manufacturers can streamline the manufacturing process, reducing the time and effort required for each individual operation.

This leads to increased productivity and cost savings. But die sets design can be a time-consuming process due to the various number of iterations between the design and the calculation process.

With a CAE/CAD calculation system integration, engineers can directly access CAD models and perform engineering calculations, simulations, and analyses on the design. This integration helps in optimizing designs by identifying potential issues, analyzing performance, and making necessary improvements early in the design process. Engineers can simulate various scenarios and quickly iterate on design changes, leading to improved product performance and reliability.

The ability to customize objects in CAD systems is crucial for designers and engineers to meet specific requirements and preferences of their designs. Real-time object customization in Computer-Aided Design (CAD) systems was developed. [1] The proposed method aims to enhance the efficiency and effectiveness of object customization by enabling real-time feedback and interactive modifications.

To streamline the design process, a novel approach to automating design and modelling tasks in the NX Siemens environment using a custom software module called the generator module can be found [2]. The goal is to improve efficiency, and reduce human errors by automating repetitive or complex tasks within NX. To facilitate the process of injection mold design for plastic products, a CAD/CAE-integrated system is designed. The system encompasses various functionalities, including product design, mold design, and CAE analysis. [3]

The importance of knowledge-based engineering in commercial CAD/CAE systems is growing in time. [4] The benefits of incorporating engineering knowledge into the design process are: increased productivity, improved product quality, and reduced design cycle time.

Various metamodeling techniques, such as response surface methodology, kriging, and neural networks, are explored and evaluated for their suitability in capturing the structural response. [5] These metamodels act as efficient and accurate approximations, reducing the computational cost of the optimization process.

Gujarathi et al. discusses the key aspects of the common data model, including its structure, data elements, and relationships. It also outlines the necessary data transformations and mapping techniques required to facilitate the bidirectional transfer of information between CAD and CAE systems [6]. Also, in the field of sheet metal deformation several CAD/CAE integrated systems [7] can be found each of them with its own properties.

Parameterized design can be developed not only in the case of the design of single parts. There is the possibility of parameterized design of more complex equipment which, in turn, are assemblies of parts between which different constraints are defined [8].

2. THE CAE/CAD SYSTEM STRUCTURE

2.1 Concept description

This paper aims to improve the calculation and 3D modeling process of various assemblies, in this case, a progressive die for manufacturing a washer. For the calculation part, an application with a user interface was developed using Visual Studio, coded in C# programming language with the .NET framework. The purpose of the application is to simplify the dimensioning and loads checking process, with the goal of reducing calculation time and minimizing the occurrence of forced errors.

The application consists of two windows: a startup window where the input data is entered, represented by the properties of the washer (inner diameter, outer diameter, thickness, and material), and the main window where the dimensions of the component elements of the die are displayed in accordance with the input data. These dimensions from the main window of the application are then exported to a MS Excel document that is running in the background, not accessible to the user, which is a crucial thing in order to avoid errors or unintentional mistakes. This Excel document serves as the basis for parameterizing the component elements of the die in the 3D assembly.

The 3D modeling of the assembly is done using SolidEdge 2022 student edition software. This facilitates the parameterization of the assembly's elements based on the data received from Excel files and more. Parameterization allows for obtaining a different set of output data when modifying the input data, resulting in new dimensions of the die components and, consequently, a new 3D model. The 3D model represents a geometrical concept and can be modified according to the production line's needs.

2.2 Logic diagram

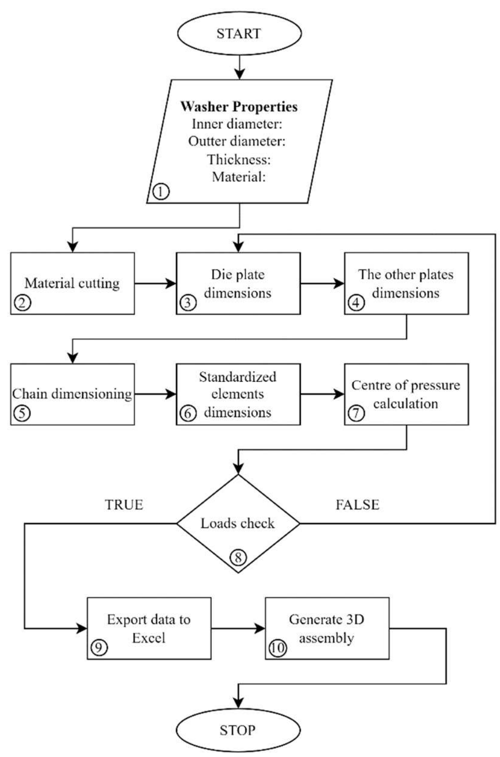


Fig.1. Logic diagram

3. THE CAE/CAD SYSTEM DESCRIPTION

Initially, for parameterizing the dimensional calculations and verification, an MS Excel form was created, which would modify the dimensions of the assembly based on the input data. This served as the initial support in creating the 3D model. However, analyzing the industry, it was noticed that Excel forms are easily prone to data corruption, as people may unintentionally modify certain values or formulas, leading to errors. This would render the spreadsheet unusable, and correcting it would be challenging since the exact location of the error needs to be determined precisely.

Taking these factors into account, it was decided to develop a user interface that would address the aforementioned issues. The application developed in Visual Studio, using the C# programming language, consists of approximately 800 lines of main code, databases for materials, screws, and other standardized elements, and auxiliary code of up to 8000 lines (variables defining, application elements, and design details). The structure of the user interface can be observed in figure 2.

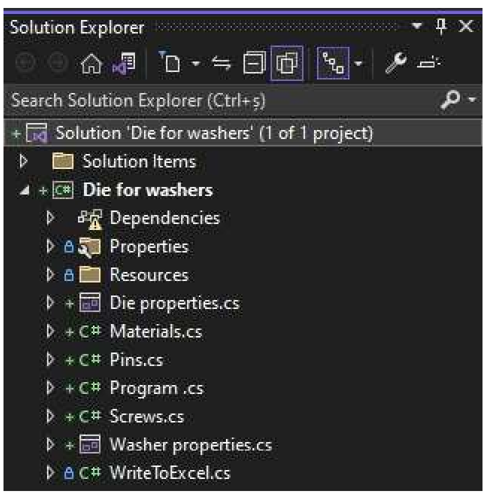


Fig.2. Application structure

After being launched, it prompts the user to enter the input data (the inner diameter of the washer, the outer diameter, the thickness, and the material which can be selected from a list). Even from the startup window, the user is guided in choosing the input data and is prevented from entering incorrect values. Once the inner diameter of the washer is entered, the application notifies the user about the acceptable range for the outer diameter. If the entered value falls outside that range, the user will be alerted. The same applies to the washer thickness. The startup window of the user interface can be seen in figure 3.

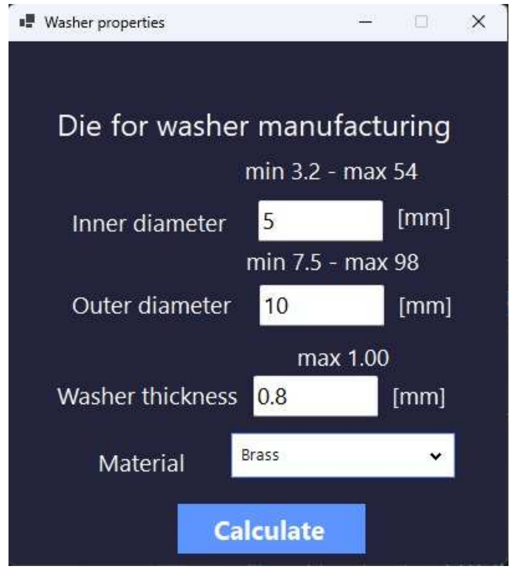


Fig.3. Startup window

Once these parameters are entered in the startup window, the application opens the main window, which is dedicated to dimensional calculations. Without any further interventions from the user, the application fully determines the dimensions of the assembly components and the dimension chains using well-established formulas in the field of cold pressing. For example, the calculation formula for the thickness of the active plate is provided in equation 1 [10].

$$H_{dp} = H_w + k * \sqrt{a+b} + (7 \dots 10)\ [mm] \quad (1)$$

Where:

H_{dp} = die plate thickness [mm]

H_w = washer thickness [mm]

k = material coefficient

a = cutting zone length [mm]

b = cutting zone width [mm]

To determine the position of the clamping pivot, the die's pressure center needs to be calculated. This is done using formula 2 [10].

$$\begin{cases} G_x = \frac{F_1*x_1+F_2*x_2+\dots+F_n*x_n}{F_1+F_2+\dots+F_n} \\ G_y = \frac{F_1*y_1+F_2*y_2+\dots+F_n*y_n}{F_1+F_2+\dots+F_n} \end{cases} \quad (2)$$

Where:

G_x = pressure center Ox coordinate [mm]

G_y = pressure center Oy coordinate [mm]

$F_{1,2,\dots,n}$ = cutting force of punch 1,2,…,n [N]

$x_{1,2,\dots,n}$ = x coordinate of punch 1,2,…,n [mm]

$y_{1,2,\dots,n}$ = y coordinate of punch 1,2,…,n [mm]

The cutting force used in equation 2 is calculated using expression 3 [10].

$$F_i = L_i * H * \sigma \ [N] \qquad (3)$$

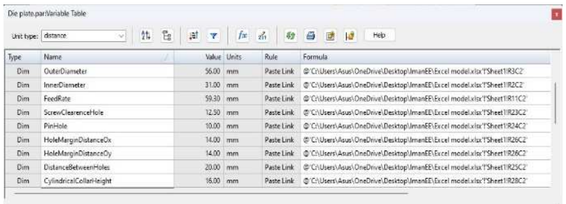
Where:

F_i = cutting force of punch i [N]
L_i = length of cutting contour [mm]
H = material thickness [mm]
σ = material tensile strength [N/mm^2]

These equations are just a few examples of the formulas that form the basis of the alogrithm. After the entire algorithm is executed, the data required for the 3D modelling of the assembly is displayed on the main window of the user interface. This data cannot be changed. The only way to change it is to go back to the start window and change the input data. A generic version of the main window can be seen in figure 4.

Fig.4. Main window

The application has the option to automatically send all the dimensions to a parameterized Excel document, which is not accessible to the user. It exists in the background, but the user cannot access or modify it, which is essential to avoid errors or unintended mistakes. The document serves as the basis for the 3D model, providing the SolidEdge software with the corresponding dimensions for each element in the assembly. Based on these dimensions, a parameterized 3D model of a die for producing a flat washer is created. This model represents a geometric concept. In addition to sizing the die's plates, this concept also facilitates the selection of standardized components, which are sized according to industry standards. With the generated model, the user, specifically the designer, is free to make dimensional modifications based on preferences, suppliers, etc., without affecting the initial assembly's parametrization. The link between the spreadsheet and the CAD system is shown in figure 5. It can be observed that the formula tab in SolidEdge gets its values from a MS Excel document. The example in the picture is for the die plate, but each component of the assembly is designed in the same way.


Die plate.par:Variable Table

Unit type: distance

Type	Name	Value	Units	Rule	Formula
Dim	OuterDiameter	56.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R3C2'
Dim	InnerDiemeter	31.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R2C2'
Dim	FeedRate	59.30	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R11C2'
Dim	ScrewClearenceHole	12.50	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R23C2'
Dim	PinHole	10.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R24C2'
Dim	HoleMarginDistanceOx	14.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R26C2'
Dim	HoleMarginDistanceOy	14.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R26C2'
Dim	DistanceBetweenHoles	20.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R25C2'
Dim	CylindricalCollarHeight	16.00	mm	Paste Link	@'C:\Users\Asus\OneDrive\Desktop\ImanEE\Excel model.xlsx'!'Sheet1!R28C2'

Fig.5. Link between CAE system and CAD system

4. CASE STUDY

In this section, a case study will be presented, to demonstrate how the CAE/CAD integrated system works and to better describe the steps it takes to transform the input data (washer properties) into output data (3D assembly of the die).

For the case study, the integrated system was used to create two washers, for comparison. The first one corresponds to an M10 screw and has the following standardized dimensions according to DIN 125 A: inner diameter of 10.5 mm, outer diameter of 20 mm, thickness of 2 mm, and the material is Stainless Steel A316. The second one corresponds to an M30 screw and has the dimensions according to the same DIN 125 A standard: inner diameter of 31 mm, outer diameter of 56 mm, thickness of 4 mm, and the material is copper. The washers to be obtained are shown in figure 6 and figure 7.

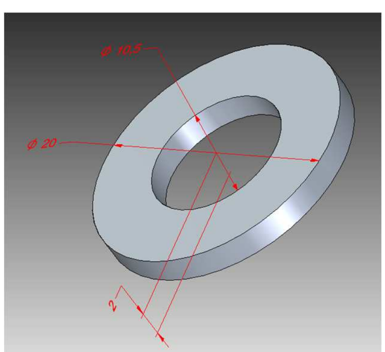


Fig.6. M10 washer

Based on the input data, the application determines the dimensional values of the components of the die and displays them in the main window.

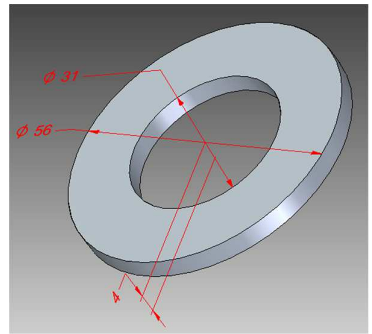


Fig.7. M30 washer

In figure 8 and figure 9, the startup window of the application is presented, corresponding to each washer. Here, the input data is entered. This is the first step after launching the application, indicated as step 1 (circled number) in Figure 1.

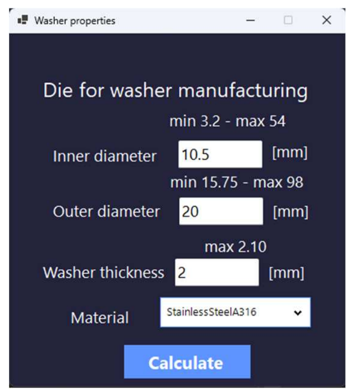


Fig.8. Startup window for M10 washer

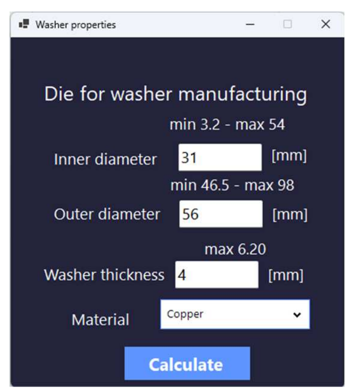


Fig.9. Startup window for M30 washer

This step corresponds to steps 2-8 in the logical diagram in figure 1. Figures 10 and 11 show the dimensional values of the active elements of the two dies, as displayed in the main window of the application.

Die plate		
k coefficient	1.3	
Calculated thickness	21.23	[mm]
Effective thickness	25	[mm]
Cutting zone - margin distance	25	[mm]
Die plate length	125	[mm]
Die plate width	85	[mm]
Cut. z. - margin effective distance	37.5	[mm]
Screw hole diameter	8.5	[mm]
Pin hole diameter	6	[mm]
Screw hole - margin distance	9	[mm]
Distance between holes	13	[mm]
Taper angle	2	[degrees]
Height of cylindrical collar	8	[mm]
Punches		
Piercing punch collar diameter	13.5	[mm]
Blanking punch collar diameter	23	[mm]
Piercing punch total length	78.4	[mm]
Blanking punch total length	78.4	[mm]
Collars height	6	[mm]

Fig.10. Cutting elements dimensions for M10 washer

Die plate		
k coefficient	1.3	
Calculated thickness	28.83	[mm]
Effective thickness	30	[mm]
Cutting zone - margin distance	30	[mm]
Die plate length	200	[mm]
Die plate width	130	[mm]
Cut. z. - margin effective distance	45	[mm]
Screw hole diameter	12.5	[mm]
Pin hole diameter	10	[mm]
Screw hole - margin distance	14	[mm]
Distance between holes	20	[mm]
Taper angle	2	[degrees]
Height of cylindrical collar	16	[mm]
Punches		
Piercing punch collar diameter	34	[mm]
Blanking punch collar diameter	59	[mm]
Piercing punch total length	91.8	[mm]
Blanking punch total length	91.8	[mm]
Collars height	6	[mm]

Fig.11. Cutting elements dimensions for M30 washer

All the data calculated according to the algorithm is then exported to an Excel document, which is linked to the CAD program SolidEdge, as shown in the example in figure 5. Figures 12 and 13 present the Excel document. It can be observed that the values in the document are identical to those in the user interface. It is worth noting again that this document is not accessible to the user, its purpose is to facilitate the transfer of data between the application and the CAD program. This part corresponds to step 9 in the logical flowchart shown in figure 1.

Lower die set		
Die plate		
k coefficient	1.3	
Calculated thickness	21.23	mm
Effective thickness	25	mm
Cutting zone - margin distance	25	mm
Die plate length	125	mm
Die plate width	85	mm
Cutting zone - margin effective distance	37.5	mm
Screw hole diameter	8.5	mm
Pin hole diameter	6	mm
Distance between holes	13	mm
Screw hole - margin distance	9	mm
Taper angle	2	degrees
Heigth of cylindrical collar	8	mm
Punches		
Piercing punch collar diameter	13.5	mm
Blanking punch collar diameter	23	mm
Piercing punch total length	78.4	mm
Blanking punch total length	78.4	mm
Collars heigth	6	mm

Fig.12. The spreadsheet of the M10 washer

Lower die set		
Die plate		
k coefficient	1.3	
Calculated thickness	28.83	mm
Effective thickness	30	mm
Cutting zone - margin distance	30	mm
Die plate length	200	mm
Die plate width	130	mm
Cutting zone - margin effective distance	45	mm
Screw hole diameter	12.5	mm
Pin hole diameter	10	mm
Distance between holes	20	mm
Screw hole - margin distance	14	mm
Taper angle	2	degrees
Heigth of cylindrical collar	16	mm
Punches		
Piercing punch collar diameter	34	mm
Blanking punch collar diameter	53	mm
Piercing punch total length	91.8	mm
Blanking punch total length	91.8	mm
Collars heigth	6	mm

Fig.13. The spreadsheet of the M30 washer

Similarly, the dimensions for all the components of the die are calculated, and then the 3D model of the assembly is generated. When the input data is modified, the assembly will be updated with the newly calculated values by the application. This step is numbered as 10 in Figure 1. Figures 14 and 15 present the 3D models of the assemblies for the two dies.

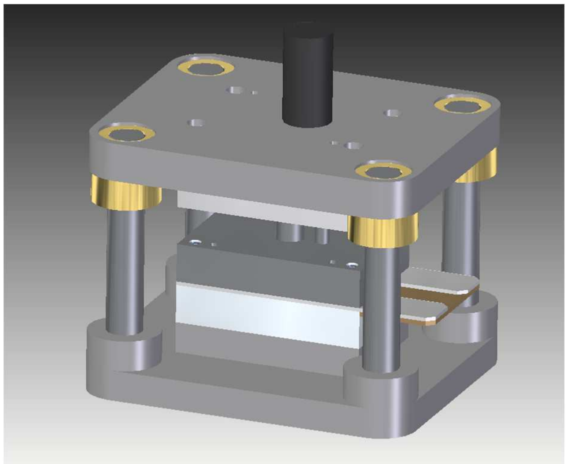


Fig.14. 3D assembly of the M10 washer die

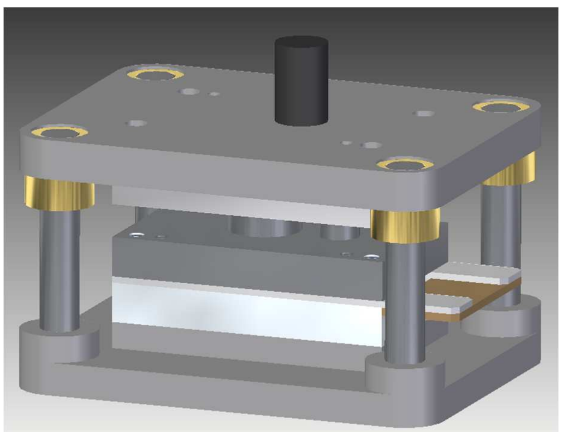


Fig.15. 3D assembly of the M30 washer die

5. USER INTERFACE CODE

In this section, a part of the code is presented. This is a brief example of what stands behind the user interface.

```
using System.Data;
using System.Windows.Forms;
namespace WasherDie
{
   public partial class DieDimensions : Form
...
//Upper plate
          up_thickness.Text =
dp_thickness.Value().ToString();
          double F_tot1, F_tot2, F1, F2;
          F1 = Math.PI * innerDiameter.Value() *
washer_thickness.Value()                        *
tensileStrength.Value();
          F_tot1 = 1.1 * F1;
2).ToString();
//Punches
...
   listOfObjectsToWriteToExcel.Add(bp_thick
ness.Value());
WriteToExcel.WriteToFile(listOfObjectsToWri
teToExcel);
          MessageBox.Show("The data has been
successfully exported. \nNow you can open the
assembly.");
       }
       private    void
WasherDie_UI_FormClosing(object      sender,
FormClosingEventArgs e)
       {
          Application.Exit();
       }
}
```

6. CONCLUSION

This integrated CAE/CAD system is a proof of concept. Its purpose is to streamline the calculation and design process and assist the designer in saving time required for calculations and the design process. Besides saving time, it also helps a lot because it leaves no room for errors, as the whole process is done by the application, without human intervention. It proves to be very useful when it comes to creating parts that belong to the same part family, in this case, washers. Once the assembly for one element of the part family is created, the design of the other elements can be done simply by entering the new properties of the elements (material and dimensions). The system has achieved its intended goal. The design of a die for washer manufacturing is simple so it would be inefficient to implement it in the industry at this stage, but it represents a starting point in our research. Future prospects include implementing this system in the design of other assemblies, such as dies for parts with more complex geometry and plastic injection molds. Our application would prove very efficient when it comes to the design of plastic injection molds for ski boots. Once the design of the mold for one model of ski boots is completed, you could create molds for different sizes of the same model, simply by introducing new input data, which would be the size of the ski boot. At that point, implementing our 'software' in the industry would prove to be eficient by saving time and by leaving no room for errors. Other applications include items for general use, like water cans, plastic barrels, plastic bins, etc.

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Sistem integrat CAE/CAD pentru proiectarea parametrizată a ansamblelor mecanice

Proiectarea corectă și rapidă a unor ansambluri în vederea execuției și implementării lor în mediul industrial este unul din dezideratele mediului economic. Lucrarea prezintă un sistem CAE/ CAD de proiectare a unui ansamblu, realizat cu ajutorul unei aplicații proprii (interfață cu utilizatorul) în limbajul de programare C#. Pentru a facilita realizarea memoriului tehnic de calcul, acesta a fost implementat într-un program de calcul tabelar care preia informațiile din interfața cu utilizatorul. Acest lucru servește, atât la păstrarea datelor într-un format digital, ușor accesibil, cât și la modificarea în timp real a datelor și a rezultatelor, nefiind nevoie de repetarea calculelor. Astfel, proiectantul câștigă timp, nefiind nevoit să refacă calculele atunci când apar erori sau la modificarea unuia dintre parametri.

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