

Development of integrated intelligent CAD system for synthesis and stress-deformation analysis of pressure vessels

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Abstract

This paper presents the process of developing an integrated intelligent CAD system (IICAD) for synthesis and stress-deformation analysis of pressure vessels. The name of the system is IICAD PP system. The goal of the paper is to present procedures and steps to develop IICAD system for specific type of products. These procedures and steps can be used to develop IICAD system for any type of specific products or family of products. IICAD PP system can help engineers during calculation and design of pressure vessels. The paper shows that IICAD PP system enables quick calculations of design parameters, automatic generations of 3D geometrical model and automatic conduction of numerical analysis for stress and deformation. All these design activities take a lot of time from engineers if they are done using conventional methods.

Keywords: C#; CATIA; Integrated Intelligent Cad (IICAD) System; Mechanical Design; Pressure Vessels.

1. Introduction

The basic precondition which every company needs to satisfy to be successful is to keep the existing market and eventually to expand it. To succeed, it is necessary to fulfil the demands of the market for long periods. The market continuously puts more complex demands in terms of quality and productivity of designing new products [1]. Dominant factors influencing on the success of a company are: product quality, speed of development and product innovation, cost-effectiveness in all aspects of the company, and presence in international markets. Increasing complexity of products which are designed, and the use of new technologies, methodologies and materials, require increasing computer support of the design process. Consequently, there is a need for: a quality scientific approach and a better understanding of the design process, use of many software-based design tools, interaction between these tools, and better cooperation between engineers. A lot of practical examples which integrate all these components have already been developed. [2-5]

Designing process has a large impact on the cost of the production process, and therefore on the profit and the entire business of a manufacturing company. This is why a large number of scientific research, which is aimed to improve production, put focus to the field of computer-aided design (CAD) [6-9]. Research motivated by increasing productivity has resulted in intensive research in the field of CAD. For the purposes of collecting and formalizing knowledge of design in the form of a set of rules and procedures which can be expressed in the form of computer software, there is a need to develop different computer systems which can support mechanical design. Such modular and flexible systems allow an engineer to design a specific product using the tools available. Such a system becomes an active participant in the design process. [7].

The above-mentioned systems are often called integrated intelligent CAD systems (IICAD) and are usually developed for a spe-

cific product or family of similar products [10-13]. This paper presents the process of developing IICAD system for synthesis and stress-deformation analysis of pressure vessels of the type shown in Figure 2. The name of the system is IICAD PP system. By examining research of other authors, it can be noticed that there isn't a lot of research with integrated intelligent computer-aided design as main topic.

2. IICAD PP system

Development of integrated intelligent CAD system for synthesis and stress-deformation analysis of pressure vessels was carried out through several phases:

- Identification of problems and goals,
- Development of mathematical models,
- Development of a parametric 3D geometry model,
- Development of numerical models for stress and deformation analysis,
- User interface design of a system,
- Implementation of the system (coding).

2.1. Identification of problems and goals

Pressure vessel design and analysis process takes a lot of time from engineers [14], [15]. To automate this process, an integrated intelligent interactive computer system has been developed. This system enables quick calculations of pressure vessel, automatic generations of 3D model and automatic generation of results for numerical analysis. Architecture of IICAD PP system is given in Figure 1.

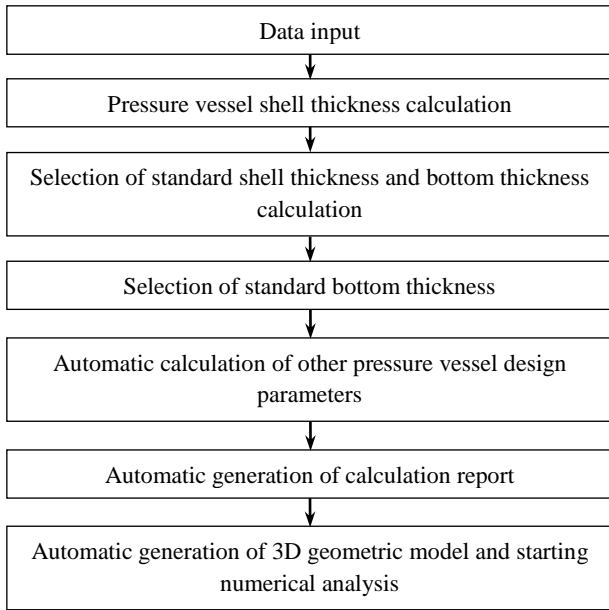


Fig. 1: Architecture of IICAD PP System.

2.2. Development of mathematical models

Calculation of pressure vessels shown in Figure 2 can be done using the procedure shown in [15]. This calculation procedure is implemented in IICAD PP system.

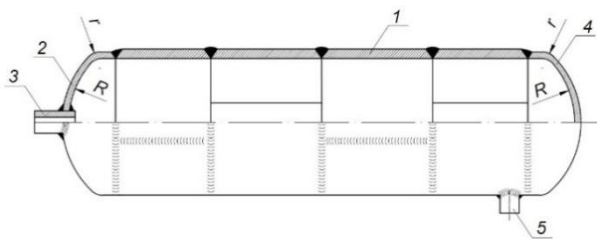


Fig. 2: Pressure Vessel: 1 = Shell, 2 = Bottom, 3 = Connection Pipe, 4 = Bottom, 5 = Exit Pipe.

Analyses of welded joints on these pressure vessels are not taken into consideration in this paper. The goal was to develop a computer system for synthesis and stress-deformation analysis of pressure vessels considering that these vessels are made as one piece. This assumption can be taken into consideration due to the following facts:

- Calculation of welded joints in numerical models is done in such a way that the welds are modelled as separate parts, and then connected to other parts in the assembly using a fix connection. Using a fix connection between welds and other parts, the numerical model gives the same results as in the case of use of a pressure vessel modelled as one part.
- By testing numerical model with welds and model without welds, we can see that the results are the same.

Calculation of pressure vessels is done using the following procedure [15].

Input data:

- Allowed operating pressure: P (MPa),
- Pressure vessel diameter: D_v (mm),
- Pressure vessel length: L (mm),
- Operating temperature: T (°C).

Minimum shell thickness δ for cylindrical shell pressure vessel can be calculated by:

$$\delta = \frac{D_u \cdot p}{2 \cdot \frac{\sigma_v}{S} \cdot \phi_2 \cdot p} + C_1 + C_2 + C_3 \text{ (mm)} \tag{1}$$

Where:

- σ_v (MPa) – Material yield strength,
- S – Degree of safety,
- ϕ_2 – weld weakening factor,
- C_1 (mm) – addition for negative deviations of shell thickness,
- C_2 (mm) – addition for corrosion,
- C_3 (mm) – addition for cladding.

After calculation it is necessary to choose the first bigger standard value for shell thickness. Minimum bottom thickness δ_b for cylindrical shell pressure vessel can be calculated by:

$$\delta_b = \frac{D_v \cdot p \cdot \beta}{2 \cdot \frac{\sigma_v}{S} \cdot \phi_2} + C_1 + C_2 + C_3 + C_4 \text{ (mm)} \tag{2}$$

Where:

- $D_v = D_u + 2 \cdot \delta$ (mm) – outer diameter of pressure vessel,
- β – bottom type calculation coefficient,
- C_3 (mm) – addition for outer pressure,
- C_4 (mm) – addition for other design coefficients.

After calculation it is necessary to choose the first bigger standard value for bottom thickness. Other design parameters can be calculated by in the case of deep bottom:

$$R = 0,8 \cdot D_v \text{ (mm)}, \tag{3}$$

$$r = 0,1 \cdot D_v \text{ (mm)}, \tag{4}$$

And in the case of shallow bottom:

$$R = D_v \text{ (mm)}, \tag{5}$$

$$r = 0,1 \cdot D_v \text{ (mm)}. \tag{6}$$

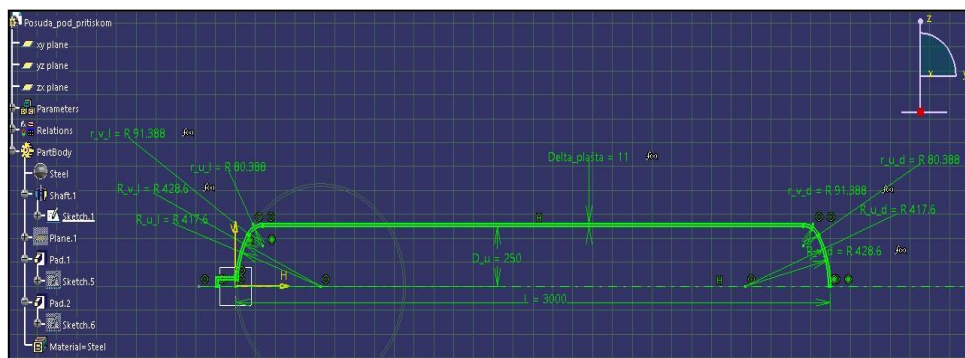


Fig. 3: Sketch.1.

2.3. Development of a parametric 3D geometry model

Before numerical analysis it is necessary to develop a parametric 3D geometrical model of pressure vessel. CATIA software is used for model development. Pressure vessel is modelled as one part. An easier way to model this type of geometry is using Shaft command. Before Shaft command it is necessary to create Sketch.1 using geometry shown at Figure 3. After Sketch.1 creation, Shaft command is used (Figure 4).

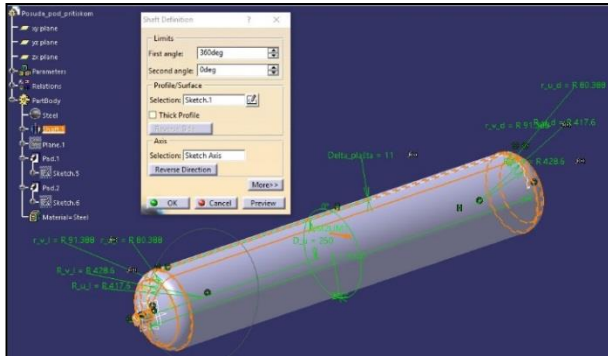


Fig. 4: Shaft Command.

The next step in modelling process is creation of pressure vessel supports. To model supports it is necessary to create a new plane. The new plane will be used to create a new sketch. Supports are modelled using Pad command. The last step in pressure vessel modelling process is to create a flat surface at the bottom of pressure vessel supports. To create this flat surface, Sketch and Pad commands are used (Figure 5).

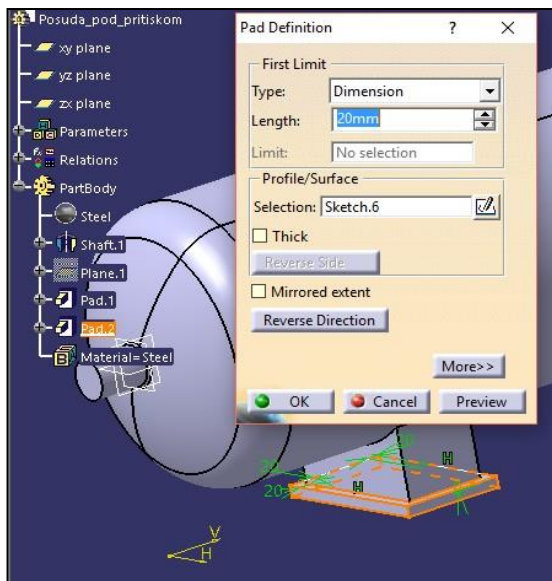


Fig. 5: Creations of Flat Surfaces at the Bottom of Supports.

To enable connection between IICAD PP system and this 3D geometric model it is necessary to make this model parametric. Parametric model, in relation to nonparametric model, has one big advantage: it is fully mathematically defined and controllable, because of which it can be connected to IICAD PP system. The first step is to rename all geometrical values in all sketches (create geometric parameters) (Figure 6). These created parameters can be automatically connected with the parameters in the table of parameters.

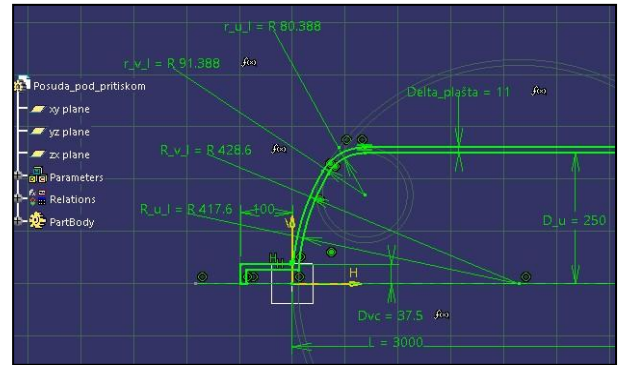


Fig. 6: Creations of Geometric Parameters.

Beside geometric parameters, it is necessary to create two additional parameters: a parameter σ_y and a parameter δ . These parameters can be created using Formula command (Figure 7).

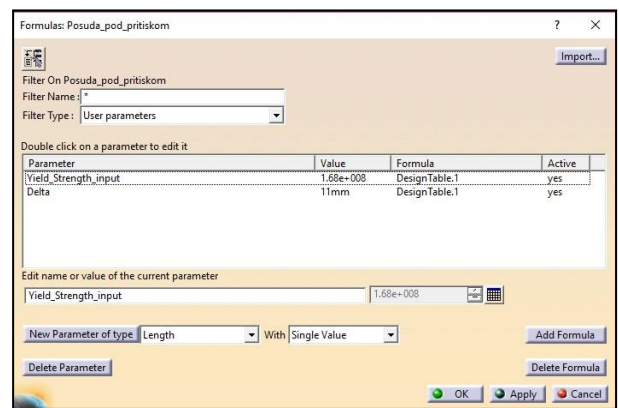


Fig. 7: Creation of Parameters Using Formula Command.

As it can be seen, CATIA enables to create parameters which are not geometrically connected to the model; these parameters can be used to additionally describe some properties of the model, properties such as material yield strength, specific density, etc. After all parameters creations, it is necessary to create a mathematical equation to calculate other geometrical values for the pressure vessel (Figure 8).

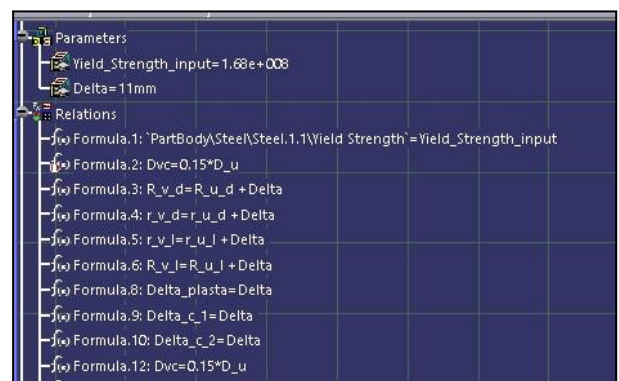


Fig. 8: Created Parameters and Relations.

Parameterization process is finished by creation of table with all parameters inside using Table command. It is necessary to choose option Create a design table from the pre-existing file; using this option, it is possible to link this table with Excel table which is already created using IICAD PP system. This table will be automatically updated from IICAD PP system after every calculation.

2.4. Development of numerical models for stress and deformation analysis

After development of geometrical 3D parametric model, it is necessary to develop a numerical model for stress and deformation analysis. Numerical model implies creation of all elements relevant for numerical analysis of pressure vessel. These elements are: material properties, supports, loads, finite element, mesh and results interpretation. In this way, a user of IICAD PP system can automatically carry out an analysis of stress and deformation for designed pressure vessel and make some modification if results are not as expected. Numerical analysis is done using Generative Structural Analysis module in CATIA.

The first step is to create finite element mesh using OCTREE Tetrahedron Mesh command. 3D parabolic element is used (Figure 9).

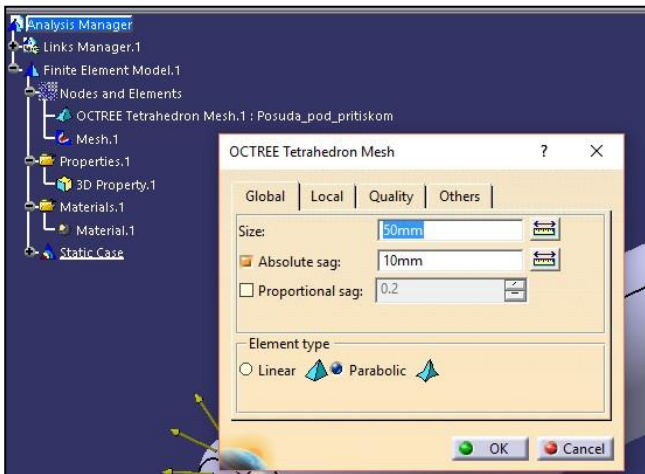


Fig. 9: Creating Finite Element Mesh.

The second step is to put supports and loads. It is necessary to put Clamp support to the bottom of flat surface on pressure vessel supports and to put Pressure load on all surfaces of shell with the direction to outside (Figure 10).

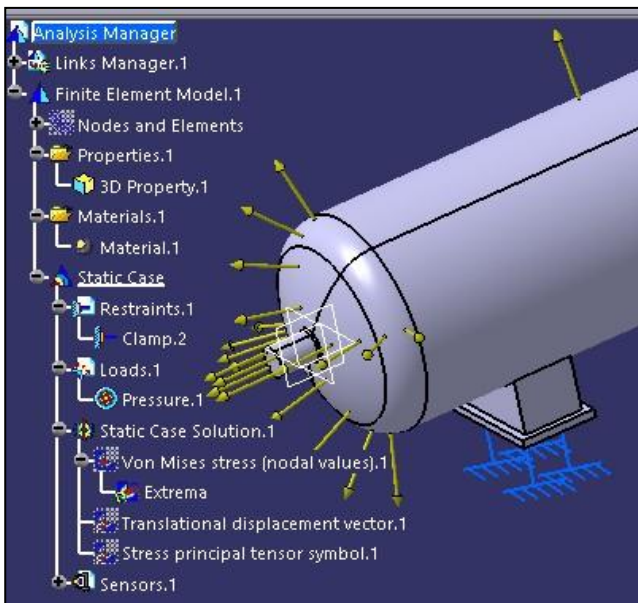


Fig. 10: Supports and Loads.

The final step of numerical analysis is to define which results will be shown. It is set to show results for Von Mises stress, displacements and principal stress. The results of numerical analysis for a specific case of pressure vessel size and loads are shown in Figure 11.

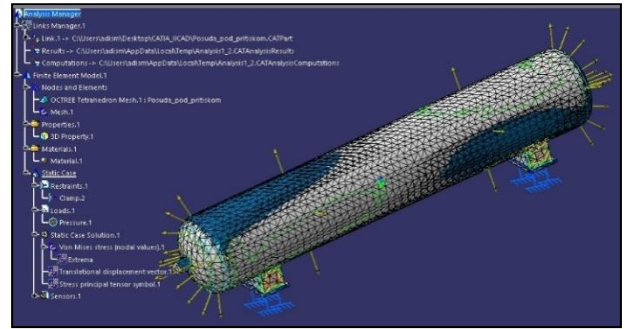


Fig. 11: Results of Numerical Analysis (Von Mises Stress).

2.5. User interface design of a system

IICAD PP system is designed through two forms: home form (Figure 12) and main form (Figure 13).



Fig. 12: Home Form.

Home form has only one drop-down menu. Using this drop-down menu, the user can create a new file or close the system. Main form has several parts. On the top of the main form there is a ribbon with Open and save buttons. Using these buttons, the user can open already saved data or save current data.

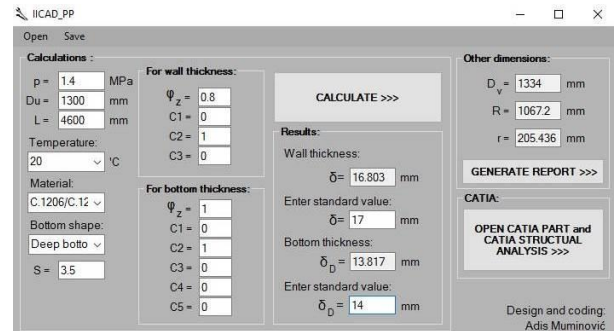


Fig. 13: Main Form.

The first step in design and analysis process of pressure vessel is to enter input data after which the user can click on the button CALCULATE and the system will calculate shell thickness. Next step is to choose the first bigger standard value for shell thickness, after which the system will automatically calculate bottom thickness. After the user chooses the first bigger standard value for bottom thickness, the system will automatically calculate other design parameters of pressure vessel. After calculation, the user can automatically generate a full report of calculation in the form of .docx file by clicking on the button GENERATE REPORT. Final step is to automatically generate 3D geometric model of pressure vessel and to start numerical analysis by clicking on the button OPEN CATIA PART and CATIA STRUCTURAL ANALYSIS. As it can be seen from the above, using IICAD PP system the user can carry out full design process and numerical analysis of pressure vessel through just a few clicks. This process usually takes days, in some cases even months of work.

3. Conclusion

Product design process, as a part of development process of product, must be done taking in consideration all necessary aspects (analysis of market, technical, technology, functional, economical, ergonomic, aesthetic and productivity properties). It is a complex process which includes a lot of modern procedures which must be carried out by teamwork of many engineers and designers with various types of background. In last few years, computer-aided design (CAD), computer-aided manufacturing (CAM), and product data management (PDM), including their integration, are in focus of research with the goal to increase the level of automation of design and manufacturing process. Some of CAD systems (NX, CATIA, Pro/ENGINEER) already have some functions for integrated product design (connection with analytical calculation, connection with parametric 3D models based on productivity properties, connection with CAM, etc.), but most of them still use classical conventional methods for product design which usually must be carried out sequentially. Sequential and non-intelligent approach is time consuming and expensive, it does not take in consideration automation of product design and manufacturing either. To define an economically and ergonomically sustainable design solution, it is necessary to perform all steps at the same time (planning, design, ergonomic and economic analysis). Competitive engineering (CE) points out that it is necessary to continuously consider additional demands, which can appear later, from the beginning of design process; it is also necessary to have continuous information exchange between all participants in design process. All demands mentioned above can be achieved by development of intelligent integrated CAD systems like IICAD system presented in this paper. The goal of the paper is to present procedures and steps to develop IICAD system for specific type of products. These steps and procedures can be used to develop IICAD system for any type of specific products or family of products. The paper presented IICAD PP system, a system which can help engineers during calculation and design of pressure vessels. From the paper we can see that IICAD PP system enables quick calculations of design parameters, automatic generations of 3D geometrical model and automatic conduction of numerical analysis of stress and deformation. All these design processes take a lot of time from engineers if they are done using conventional methods. From this paper it can be seen that development of IICAD systems is justified and it can be expected in the future that these systems will be developed in small companies for calculations and design of specific products. Future development of IICAD PP system can go in several directions, to include welded joints, to include automatic generations of technical documentation for designed pressure vessel or to include different types of pressure vessels.

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