Solar Panel Optimization of a Parabolic Channel to Generate Electrical Energy

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***Abstract*—In a conventional design process, several methodologies can be applied to optimize the design; however, these methods may be slow and too dependent on the designer´s expertise and the project limitations. Furthermore, some methodologies are mainly based on trial and error, thereby making them slow and inaccurate. Many techniques are fundamentally based on the decisions derived from the designer's criteria, such as the specification of what is to be modified (e.g., material, geometry, dimensions). As a result, the final design may not be based on an optimization analysis that leads to a better design.**

In preparing for a mechanical design, aspects such as shape, dimensions, and topology are analyzed; heavy production demands force the designer to identify new methods and tools that allow him to optimize his work and its results, including the elements, machines, and structures. With the recent development of computational tools, topologic optimization and the finite element method are now possible, among other techniques.

This paper presents the use of a finite element method to conduct a topologic optimization using the SolidWorks software, with the goal of optimizing the solar panel thickness in a solar collector.

***Index Terms*—Optimization, finite element, mechanical design, panels, dimensions.**

I. Introduction

Man, with his ongoing quest of life and due to his intelligence, has learned to take advantage of nature in a rational manner and to face problems of optimization in an intuitive manner. Thus, man has improved his tools, acquired protection and shelter, and improved his environment.

Activities in topologic optimization originated after World War II, and according to the literature it was made possible as a result of operations research used by the military services deployed at the beginning of the war.

During the war effort there was an urgent need to assign, in the most effective way possible, limited resources to diverse military operations and to the activities inside these operations. By the end of the war, the success of research into optimization generated a great interest in its applications outside the military field, and it has been successfully applied in mechanical design

The methods of optimization can be classified as classic methods (such as linear programming, nonlinear, dynamic, and stochastic techniques) and heuristic methods that are based on phenomena observed in nature, such as evolutionary algorithms.

Linear programming is used to solve problems where every relationship between the variables is linear in its restrictions, as with the objective functions. The objective of linear programming is to optimize (*minimize or maximize)* a linear function of *n* variables subject to the linear restrictions of equality or inequality; this is named the *objective function*. In linear programming there are four distinguishing components [1]:

- The data set
- A variables set that is involved in the problem, next to their respective defined domains
- The linear restrictions set for the problem that defines the admissible solution set
- The linear function that must be optimized (*minimized or maximized*)

Genetic algorithms are a subset of optimization methods and have been used to solve a wide array of problems. One can say that genetic algorithms are search algorithms based on the mechanism of natural selection and natural genetics [2]. They combine the survival of the most compatible chain structures with a random information structure, exchanged in order to build a search algorithm with some of the innovation capacities of human search.

II. Methodology

Introduction to optimization

During the past decades, design engineers have learned to use and trust the tools of computer assisted engineering (CAE), such as finite element analysis (FEA), computational fluid dynamics (CFD), and movement simulations, to assist in producing better designs faster. They know that such tools will help them to design components, ensembles, and products that will endure heavy activity.

However, it is possible that products designed to endure the "worst case scenario" are not the best designs for a real-life environment. In order to comply with the requisites of security and strength, it is possible that the design becomes too excessive or heavy for its purpose, or too difficult and

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costly to build. The design engineer who wants to design the best products at the lowest cost for their labor must take a step ahead and use CAE in the development of products to conduct an optimization.

Optimization for design engineers

Design optimization can increase the value of a product by improving its functionality in its operative environment and lowering its cost of production by reducing the amount of material used in the manufacturing process [4,5].

The design engineer is, by definition, working at the state of the art of product development. Today, the engineer is familiar with design analysis, which means that he has the basic knowledge to use optimization and he only needs optimization tools to take the next step.

With the use of optimization, the design engineer will increase his knowledge of the behaviour of his product and will improve the design based on the data from the previous analysis.

Fundamental elements of the optimization

The optimization process has three main components:

- Objective
- Restrictions
- Variables

Stated simply, the optimized design should maximize or minimize the objective by changing the variables while keeping the answers within the defined restrictions in a critical manner [3,4].

Objective: The objective is the purpose of the optimization; for example, if a company investigation shows that it will gain a competitive advantage by producing a lighter or less expensive product, then reducing the weight or the cost of the product becomes the optimization objective. This case is called a one-objective optimization.

Often engineers have to face several objective optimizations; however, if the optimization demands more resources than are available, the design engineer may be able to adjust the definition of the problem to one objective (or one objective at a time) to simplify the optimization process.

In most cases, engineers who work with structural design have as their objective the minimization of weight. In fluid dynamics applications, the most common objective is to minimize the pressure drop and the turbulent energy or to maximize the speed.

Restrictions: Restrictions can supply realism to the optimization. If the optimized problem is restricted to a minimization of the weight without constraints, the program will automatically select the minimal material condition allowed by the variable costs; however, in the real world most pieces have other operational requisites, such as resistance or rigidity.

For this reason engineers must select restrictions based on their relative importance, in order to have a piece behaving properly according to the system. The selected restrictions usually are those that are allowable in a single static, frequency, or thermal analysis.

Design Variables: In an optimization study, the engineer needs to be able to change the design parameters if he expects to find the best of many possible configurations. These parameters are the design variables, and can include the costs, the number of entries of a matrix, the material properties, the charges, the rigidly of the spring, or any other aspect of a design that can be improved or can obtain a better value.

The variables can be continuous, which means that they can assume any value between a minimum and a maximum specific value. Most cost variables belong to the continuous category.

Variables can also be discrete, which means that they have a defined set of possible values. The simplest discrete variable is an activate-deactivate variable or a yes-no variable; for instance, the presence or lack of a closure or welding belongs to the category of discrete variables. Other examples include instances of a pattern or, for example, a pole or wheel that can have any number of radii except 3,2 or 4,7.

Metal lamina calibers are an example of a variable that can belong to both categories; usually, the thickness of the caliber has predefined values but common practices specify the thickness as a continuous variable which is rounded up or down to the nearest thickness caliber.

The variable selection is a very important step in the configuration of an optimization study. If the engineer selects too many variables, or an insufficient number of variables, the efficiency of the analysis can be affected. Too many variables (a large rank) can sometimes make the process too difficult for finding the most appropriate design by the program, especially when the relative minimums and relative maximums are considered.

On the other hand, if the designer offers too few variables or a very small rank, the success of the study can be unnecessarily limited.

The most reliable method for variable selection lies in performing beginning sensitivity studies of the different possibilities.

Tool for product optimization

Optimization by FEA represents a growing field of study in engineering. Even though there are many programs and tactics available for its realization, industrial studies, sensitivity studies, and form optimization are the most commonly used today. Two methods frequently used in shape optimization are gradient search and design of experiments (DOE).

The latter is based on the response surface calculus and produces “solid” solutions that are effective in the widest range of possible conditions of service during the product’s life.

The workflow to realize a design study is represented in the flowchart in Fig. 1.

The present work presents an optimization of a parabolic chamber panel designed to harvest solar rays. This panel uses solar energy to produce water vapour and thereby generate electrical energy using a non-contaminant source.

Figure 2 shows the two components of the parabolic chamber. In the figure, structure (1) indicates the panel support and lateral support, (2) indicates the solar panels, (3)

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is the Schott tube, and (4) indicates the lateral supports of the Schott tube.

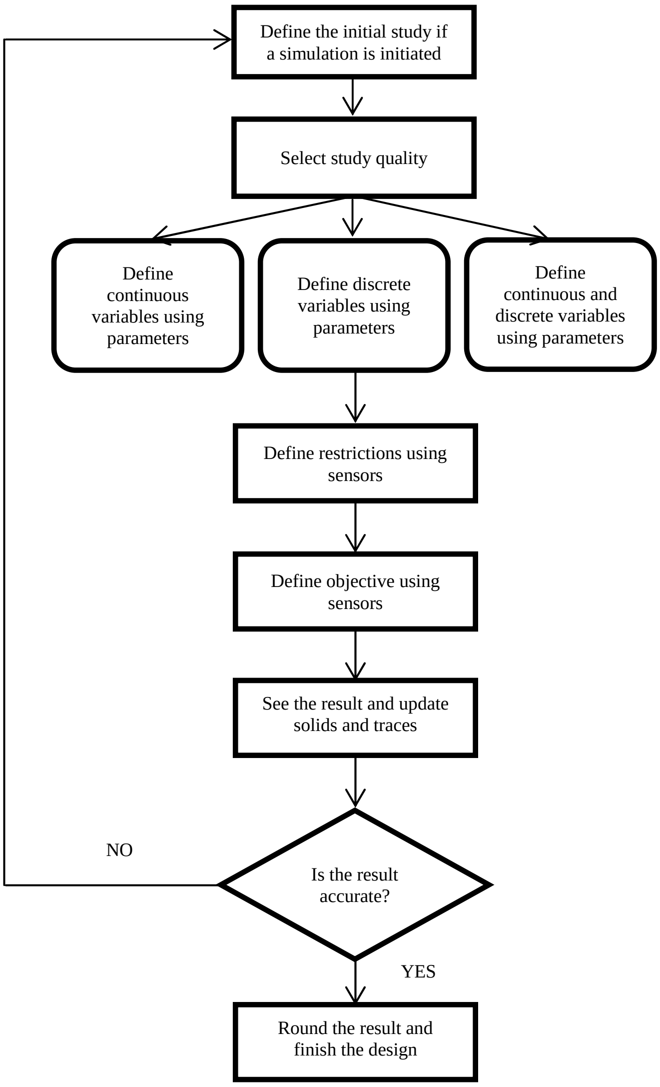

Fig.1. Optimization flowchart.

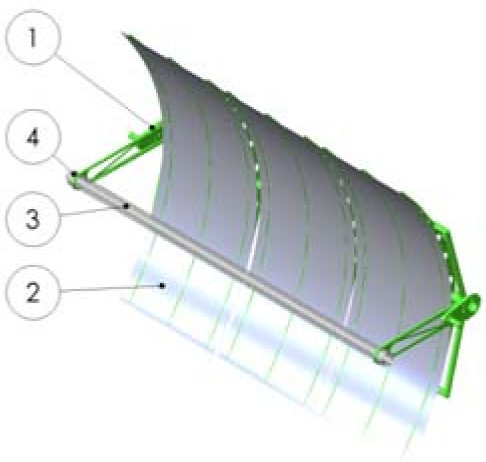

Fig. 2. Parabolic channel ensemble.

Initially, a static study of the air pressure over the canals was made. These pressures were theoretically and experimentally determined to be 177.85 N/m^2 .

The initial caliber of the panel was 18, with a thickness of 1.25 mm. It was established as a restriction that the contact area of the panel, based on the ribs that form part of the structure, is represented by a global mesh size of 55 mm with a tolerance of 2.75 mm The material of the lamina is aluminum alloy 3003 with an elastic modulus $6.9e+10\,N/m^2$, Poisson coefficient 0.33, elastic limit $41361300\,N/m^2$, and density $2700\,kg/m^3$.

The results taking into account the static analysis called Lamina C18 (-Caliber 18) are the von Mises tensions. The displacement in Y is determined by the position of the drawing in the canal and the unitary deformation.

The **von Mises tension** is a physical quantity proportional to the distortion energy. In structural engineering it is used in the context of failure theory as an indicator of a good design for ductile materials.

The von Mises tension can be calculated by taking the main tensions of the tension tensor of a deformable solid using the following expression:

$$\sigma_1 = \frac{\sigma_x+\sigma_y+\sqrt{(\sigma_x-\sigma_y)^2+4\tau_{xy}^2}}{2} \qquad (1)$$

In the case of panel analysis, the main tensions are determined by the following expression:

$$\sigma_1 = \frac{\sigma_x+\sigma_y+\sqrt{(\sigma_x-\sigma_y)^2+4\tau_{xy}^2}}{2} \qquad (2)$$

$$\sigma_2 = 0 \qquad (3)$$

$$\sigma_3 = \frac{\sigma_x+\sigma_y-\sqrt{(\sigma_x-\sigma_y)^2+4\tau_{xy}^2}}{2} \qquad (4)$$

The **u** deformations of any point of the shell can be stated generally by interpolation of the node deformities:

$$u = \begin{Bmatrix} \mathcal{U} \\ \mathcal{V} \\ \mathcal{W} \end{Bmatrix} = \sum_i \begin{Bmatrix} U_i \\ V_i \\ W_i \end{Bmatrix} N_i + \frac{\varsigma}{2}\sum_i N_i\, t_i V_n^i \qquad (5)$$

III. RESULTS

The results obtained are: von Mises tension $5017981\,N/m^2$, displacement $2.382e-002$, and unitary deformation $1.722e-004$. A graphical representation of the analysis results is presented in Fig. 3.

The optimization analysis automates the manual process of determining the configuration. The trends are rapidly detected and the optimal solution is identified in a minimal number of tests. In this optimization analysis the following input is required:

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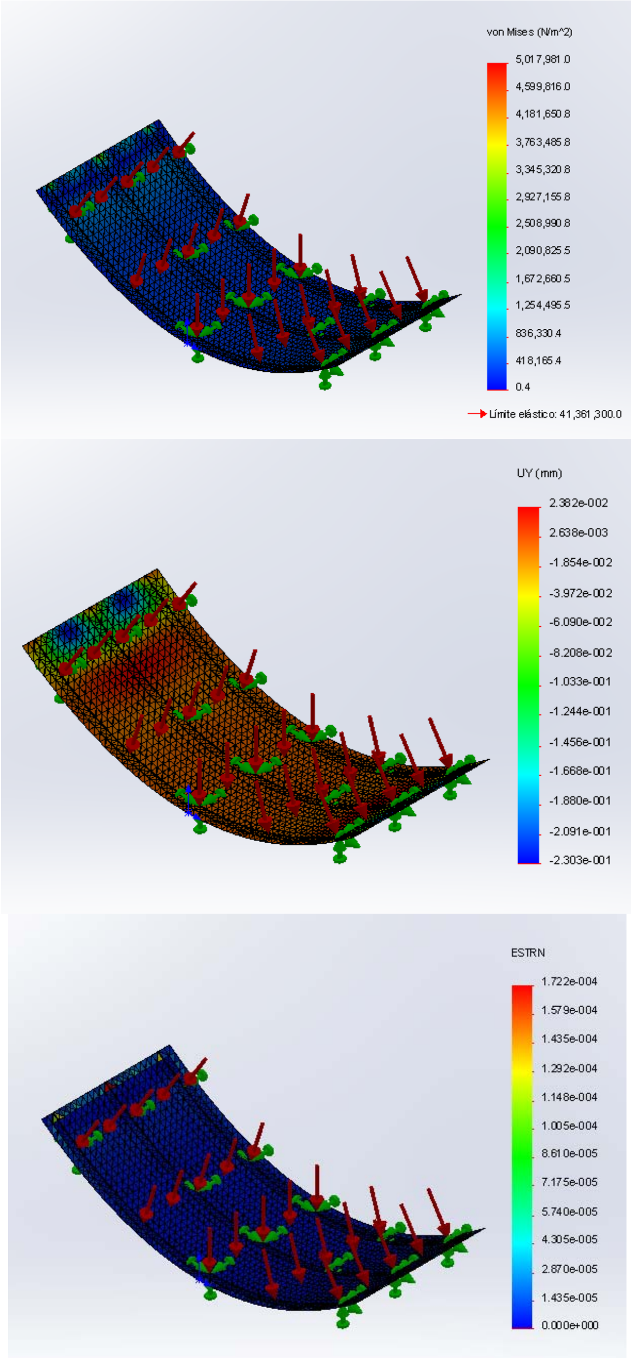

Fig. 3. Results of the static analysis, tension, displacement, and deformation.

Design variables or geometry restrictions: The parabola thickness is selected that enables it to change with its established intervals. Its values are minimum 0.71 *mm* and maximum 2.11 *mm* with a pass of 0.18 *mm*.

Behaviour Restrictions: These establish the conditions or restrictions that the optimal design must meet. The tensions are specified to be less than $4.1361e + 007\ {}^{N}/_{m^2}$. The displacements must be less than 5 *mm*, with all of them based on the Lamina C18 study.

Objective: The objective for the optimization analysis was specified to decrease the piece volume.

The optimization analysis is executed with these inputs. The program executes 11 different scenarios, including the present case and the initial case that are the same. When the program finishes it shows the 11 results and automatically shows the optimal one. For the case of the thickness of the parabola, it shows that scenario 1 is optimal if the program only runs 9 scenarios. The results for these scenarios are shown in Table 1.

Table 1. Optimization results (only 3 of the 11 scenarios).

Component Name	Units	Actual
Lamina Thickness	mm	2.11
Displacement1	mm	0.03697
Tensión1	N/m^2	7.4715e+006
Volume1	mm^3	8392163.20656

Initial	Optimal
2.11	0.71
0.03697	0.01747
7.4715e+006	4.1538e+006
8392163.20656	2824982.12709

Figure 4 shows the displacement and tension graphics for the optimal scenario.

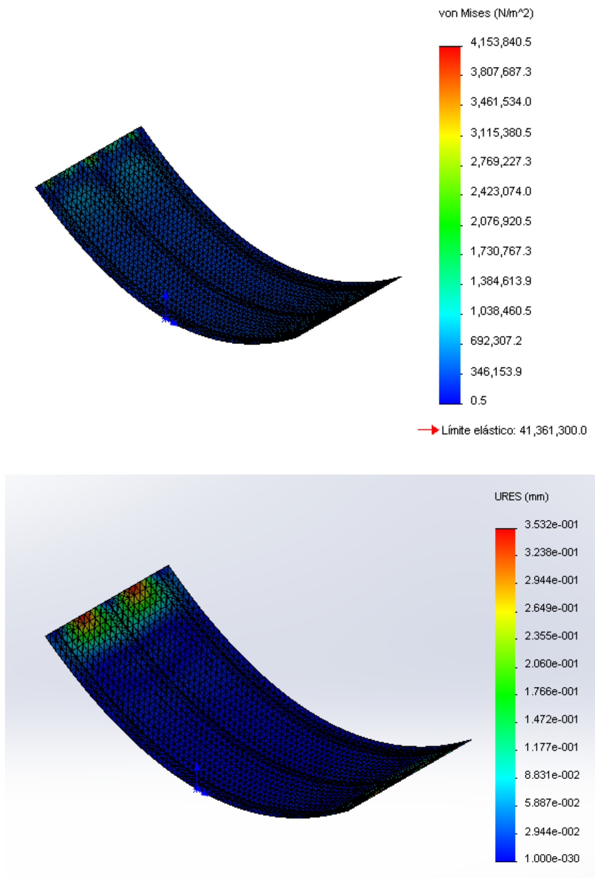

Fig. 4. Tension and displacement graphical results for the optimal scenario.

IV. CONCLUSION

The design optimization can increase the value of a product, enhance its performance in its operational environment, and reduce its cost of production through a reduction in its initial material. When optimization is used, the design engineer will increase his knowledge about the behaviour of the product and will improve it. This allows the fabrication of lighter parabolic channels because the initial C18 caliber of 1.21 *mm* thickness is reduced; its fabrication, based on the optimization, uses a C22 caliber of 0.71 *mm* thickness. The consequence is a reduction in weight, lamina cost, and project cost in general.

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