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Topological Analysis Applied to a Critical Part of the FRT-RAVE V1 CNC Machine

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Abstract

The optimization of parts allows to design robust and efficient machines consuming less material and therefore lower cost. The objective of this study is to topologically redesign a mechanical part to support a laser module and a router while maintaining the robustness required by a desktop machine without losing accuracy. As a result, the engineering analysis of a critical part is shown, demonstrating the reliability of the design.

Keywords: *Analysis, CNC, Design, Laser, Router.*

1. INTRODUCTION

The computer numerical control (CNC) appeared between the 50s and 60s in order to reduce manufacturing times of mechanical parts or components, in addition to improving accuracy, quality and low production costs at the time of manufacturing components. Initially, most companies found it difficult to access CNC technology due to its computational cost and large workspace [1], this drawback has been overcome thanks to the computational developments of the last two decades.

In modern systems end-to-end component design is highly automated using computer aided design (CAD) and computer aided manufacturing (CAM) programs, these programs produce a file that is interpreted to extract the commands needed to operate a particular machine through a post processor, and then loaded into CNC machines for production [2].

As the configuration of industrial components tends towards increasing complexity, newly developing technologies such as AM (additive manufacturing) technology has evolved thanks to its unique capabilities, such as the construction of complex geometries and design freedoms.

Rapid prototyping is a clear example that consists of creating objects with similar characteristics to the original (shape, mechanical resistance, color) in order to test the product before bringing it to the market. It is an easy and inexpensive manufacturing technique. In the civic sector, these design strategies must be clearly defined to ensure efficient use of material, easy construction, structural reliability and safety functionality of the whole system [3].

The analysis by means of the finite element method, as stated by Álvaro Remache and his work group [4], provides a solution to engineering problems, characterized by the analysis of abstract mathematical models involving different parameters.

SolidWorks presents topology studies which allows to eliminate elements of the mesh to achieve a better way of correlation between stiffness and weight. Always bounded by deformations and manufacturing controls [5].

It is important to highlight the process in Latin America on the implementation of numerical control because in universities and institutes are developing desktop machines are 3D printers, routers, laser engraving among others, as is the case of Carlos Hernandez Hernandez of the Technological Institute of Celaya in Mexico who designed and developed a machine for milling and drilling of phenolic plates using the basic principles for the movement of 3 axes (X Y Z) [6]. In Colombia, a 3-axis CNC milling machine for PCB machining with open development platforms was manufactured at the Polytechnic University of Cartagena [7]. These machines have been developed for student use, but in the case that a natural person wishes to implement his own structure, the manufacturing costs are economic and the components are easily accessible for its construction.

This article will show an engineering analysis using the topological optimization method, applied to a critical 3D printed part of the FRT-RAVE V1 CNC machine with the purpose of reducing its mass while supporting the same initial loads. During the analysis process it will be shown the savings in production time of the component and at the same time the reduction of the energy cost used by the 3D printer. It is concluded that the topology optimization process is presented as a viable alternative for new design systems on different materials to be used in industrial applications.

2. METHODOLOGY

As part of the initial process, ABS was used as a test material due to its important engineering properties, such as good mechanical strength, impact resistance, and ease of processing during part manufacturing.

First of all, the particular critical part to be analyzed was selected under the criterion of performance. Priority has been given to the components that support the elements that have movement, allowing the optimization of the input energy or consumption of the machine. Figure 1 shows the initial reference model for the development of this work.

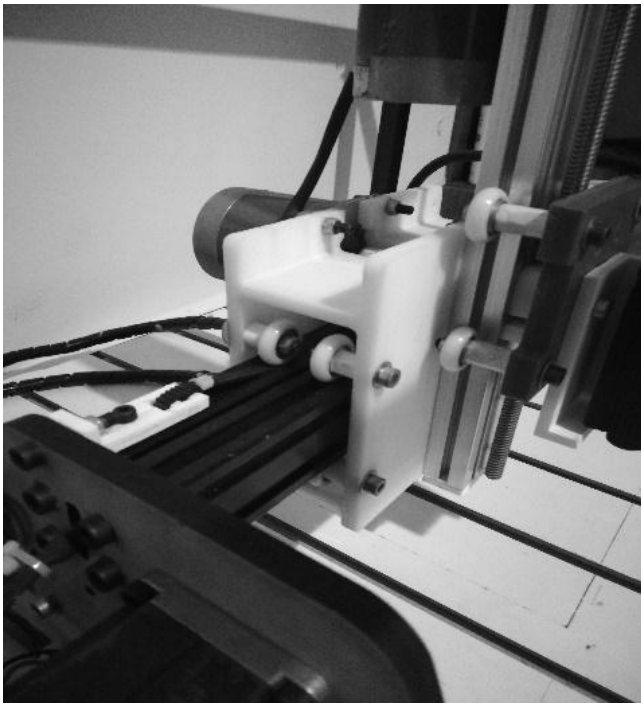

Fig. 1. X-axis component.

2.1 Engineering analysis for the X-axis part

Before the simulation of the model, it is necessary to determine the load distribution on the part, this implies the type of load (point or distributed), its orientation (the face or point where it is applied) and the support (if it is on one or more support points). Figure 2 shows the CAD of the X-axis part, which is in charge of the respective linear movement and in turn performs the function of supporting the entire Z-axis system of the machine.

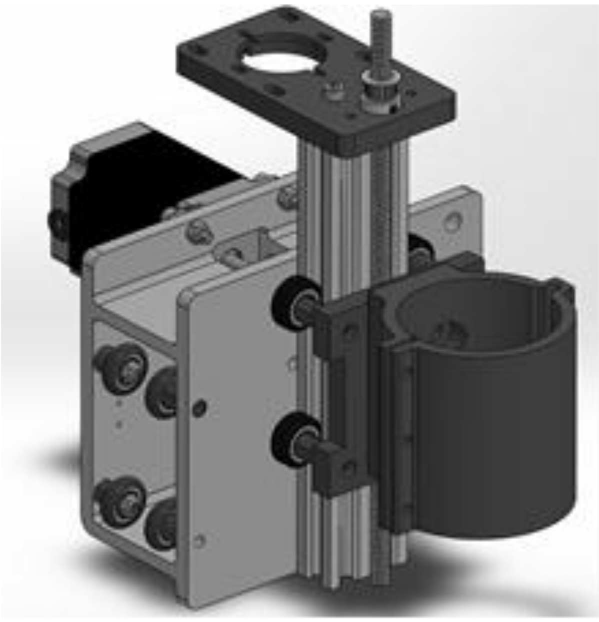

Fig. 2. X-axis component next to the Z-axis system.

2.2 Application of loads and fastenings

The components used on the X-axis support include the stepper motors, aluminum rails and the router (this being the heaviest component). These components together apply a load of approximately 27N on the totality of the supports and with the respective restrictions as can be seen in Figure 3. It is important that these loads and restrictions are placed correctly so that the topological result is adequate.

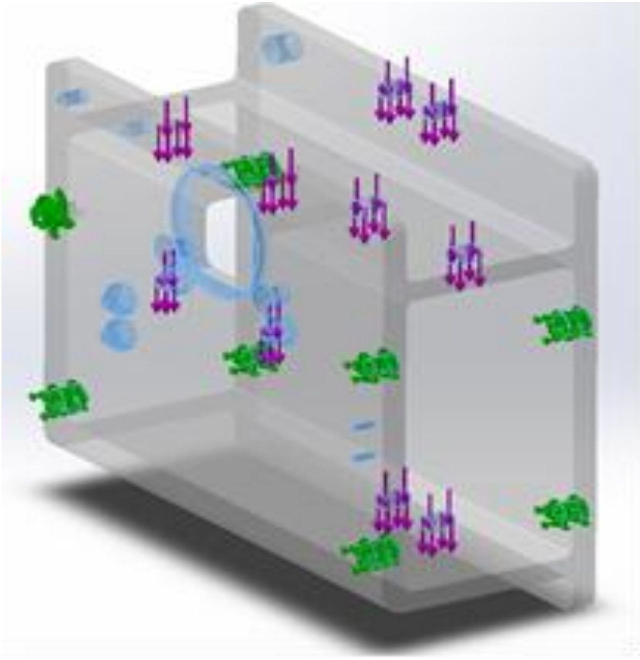

Fig. 3. X-axis part loads and fixtures.

Static analysis.

With the results obtained from the static study in Figure 4, it is evident that the safety factor is 278, which gives reason to select a topological analysis.

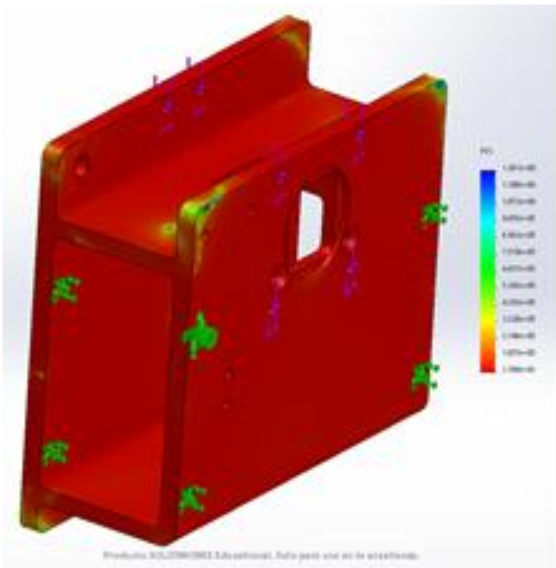

Fig. 4. X-axis piece static analysis results.

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Topological analysis

With the results obtained in the static analysis, we proceeded to perform the respective topological analysis, it was proposed to apply a mass reduction of 53% in order to save raw material and energy cost of production of the mentioned piece. Analyzing the topological study observed in Figure 5, the software shows with a color scale the areas that were removed. Under these conditions the part can be reproduced maintaining its capacity to resist the same 27 N, but for aesthetic reasons it is recommended to redesign the part and proceed again with the static study, in order to prove that the part meets the load conditions without suffering any damage.

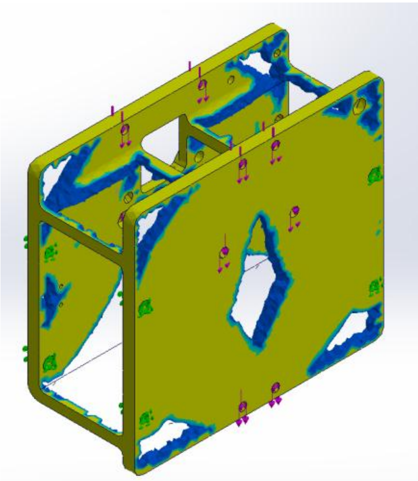
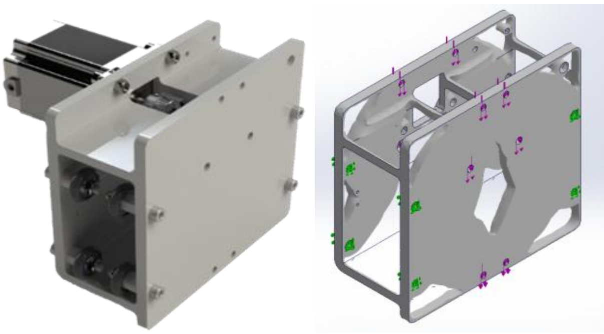


Fig. 5. 53% mass reduction in the X-axis part.

3. RESULTS

To demonstrate that the topology process is a viable method in the mass production of components, we proceed with the comparison of manufacturing times in the 3D printing process between the original part and the topological reduction part. Figure 6a is the representation of the initial design with some of its components, on the other hand, Figure 6b shows the transformation of the design by significantly reducing some sectors in order to achieve the assigned task.



a b

Fig. 6. Geometries: (a) Piece without topological analysis. (b) Part with topological analysis.

Figures 7 and 8 show the printing duration of each part using Ultimaker Cura, where the time reduction is evident on a large scale with a difference of approximately 6 hours, it should be noted that 3D printing processes are delayed and every hour that is optimized is a saving for the manufacturer.

Fig. 7. 3D printing duration of X-axis part.

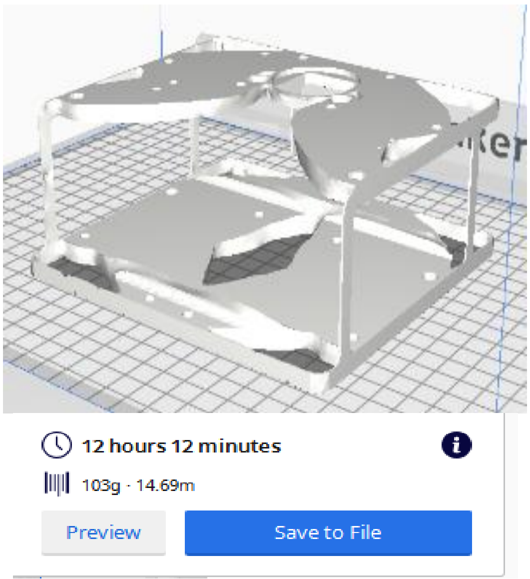


Fig. 8. 3D printing duration of optimized X-axis part.

The energy cost reduction is the next important factor in this study, because it will show how much money the designer of the part would be saving. Initially a search of the consumption of a conventional 3D printer was carried out, finding that Alfonso MC [8] through an experiment of energy consumption that he carried out on his Prusia i3 printer shows that on average it consumes between 160 KWh and 190 KWh.

Next, a search was made for the average cost of $/KWh in Colombia where the energy and gas regulation commission (CREG) for the month of April 2020 reports that the value is between $557.3105 and $666.8147 Colombian pesos [9]. Table 1 shows the consumption of each piece depending on the duration of processing, obtaining the value of energy consumption of the machine, for this process the following equation is used.

Table 1. Energy consumption of each part.

	Price $/KWh	Part without topological analysis (Construction hours)	Piece with topological analysis. (Construction hours)
	666,8147	17.59	12.12
Total consumption value of the machine ($ pesos)		11729,27	8081,79

An "energy consumption" saving of $ 3647.48 Colombian pesos is achieved without including the raw material saved by applying the topological method, by placing this project at large production stakes it will be noticed that the amount of savings will grow exponentially as more components are manufactured.

This same technique was applied to a total of 2 parts of the FRT-RAVE V1 CNC MACHINE, reducing energy and raw material consumption by 45%.

4. CONCLUSION

Topological analysis is an innovative procedure that was incorporated in the 2018 version of SolidWorks. This contribution made it possible to verify the veracity of the analyses performed on the intervened parts, allowing it to be applied in the manufacture of new machines, optimizing the use of raw material.

The computational procedures carried out in this research prove the great help that technology offers to the engineering study, as well as to the manufacture and reproduction of parts.

It is concluded that the viability of the design of a part is not based on how big and robust it is, but by applying a good design and using new technologies that arise, resistant and efficient components can be developed.

For future designs it is recommended to use this methodology in order to reduce production times of the parts and reduce the raw material to be used.

By minimizing the amount of raw material used in the manufacture of the part, a reduction in energy consumption by the printer is achieved, reducing the cost of mass reproduction.

Methodologically, it is found that the strength of the initially constructed model did not vary with the one obtained after applying the topology method.

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