DESIGNING AN ADDITIVELY MANUFACTURED STRUCTURAL COMPONENT FOR PRE-SALT EQUIPMENT

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Abstract: Equipment used in the exploration of pre-salt hydrocarbon fields can be subjected to high pressures. In this context, a structural component belonging to a seismic data acquisition device was redesigned considering the use of additive manufacturing. In this process, many geometries were obtained due to spatial constraints in the assembly of electronic components, sensors and their connections. Through numerical simulations, several tests were performed with geometries generated through topological optimization. The goal was to increase the available volume to accommodate electronic boards making the assembly easier and to reduce the component weight. At the end, this structural component called “central column” was redesigned with a superior performance than original designed component manufactured by milling.

Keywords: Additive Manufacturing; Assembly; Structural Analysis; Topology Optimization.

PROJETANDO UM COMPONENTE ESTRUTURAL POR MANUFATURA ADITIVA PARA UM EQUIPAMENTO PARA O PRÉ-SAL

Resumo: Equipamentos utilizados na exploração das reservas de hidrocarbonetos do pré-sal podem ser submetidos a pressões elevadas. Nesse contexto, um componente estrutural pertencente a um dispositivo de captura de dados sísmicos foi reprojetado considerando o uso de manufatura aditiva. Nesse processo, muitas geometrias foram obtidas devido a restrições espaciais da montagem de componentes eletrônicos, sensores e suas conexões. Através de simulações numéricas, foram realizados vários testes com geometrias geradas através de otimização topológica. O objetivo foi aumentar o espaço interno para as placas eletrônicas para facilitar a montagem e reduzir o peso do componente. Ao final, esse componente estrutural chamado de “coluna central” foi reprojetado com performance superior em relação ao projeto original fabricado por fresamento.

Palavras-chave: Manufatura Aditiva; Montagem; Análise Estrutural; Otimização Topológica.

1. INTRODUCTION

The exploration of hydrocarbon fields in the Brazilian pre-salt is a technical challenge. The enormous depth in which some equipment works causes the external pressures to be very high. Considering the characteristics and requirements of the equipment, engineers need to design with care to withstand such pressures, but without oversizing the equipment.

In this context, equipment for use in geophysical studies, used as an element for 4D seismic, allows the collection of seismic data, both passive and active, of hydrocarbon reserves in a timely manner. Such equipment, a seismic node, will be installed on the ocean floor, at depths of up to 3000 meters and must remain intact and functional for 5 years.

In the design of this seismic node, there are requirements for mass, volume, projected area on the ocean floor and many other requirements that need to be met to achieve the expected functionality and desired seismic sensitivity. Thus, the development of the project led to a cylindrical geometry, made of aluminum, where electronic components and batteries are accommodated inside. To withstand the pressure, it was necessary to manufacture a type of column in machined AISI P20 steel, which also helps organize the electronics to be inserted into the node. This column, however, has a relatively large volume and, in the assembly of the initial prototypes, it proved to be less efficient in organizing the electronics than was imagined.

Additive manufacturing (AM), also known as 3D printing, is a set of technologies that can be employed to manufacture components. Due to the characteristics of these manufacturing processes, it is possible to manufacture parts with greater geometric freedom than by other manufacturing processes [1]. In this way, it is possible to obtain parts with material optimization and unique characteristics that bring several advantages, without the need to use any specific tooling. In addition, the advancement of technologies and materials has allowed for increasingly reliable fabrication in a variety of materials [2].

Due to the limitations found in the design of the seismic node column made of machined (milled) steel, a study was carried out to replace this component. The imagined alternative was to use the advantages of additive manufacturing to produce a structural component that had a smaller volume than the current component and that would facilitate the assembly of the electronics. This work will present the development of this new seismic node column considering the additive manufacturing design and process.

1.1. Current design challenge

To better understand the challenge and component in question, Figure 1 introduces the node and column. In Fig. 1 (A) the aluminum housing is shown, with the lid highlighted in blue. The cylinder diameter is approximately half meter. In Fig. 1 (B) the node is open, where its batteries and electronics can be observed. In blue highlight, in the center of the node, the position of the column can be observed. In Fig. 1 (C) the column is presented in an isolated way. In this image, the force vectors on the upper extremities can be seen, in the transfer of the external pressure applied to the cap, to the column structure. This component, the column, must withstand the pressure exerted by the cap and have a maximum deformation of 0.8 mm in order to prevent leaks from occurring in the seals.

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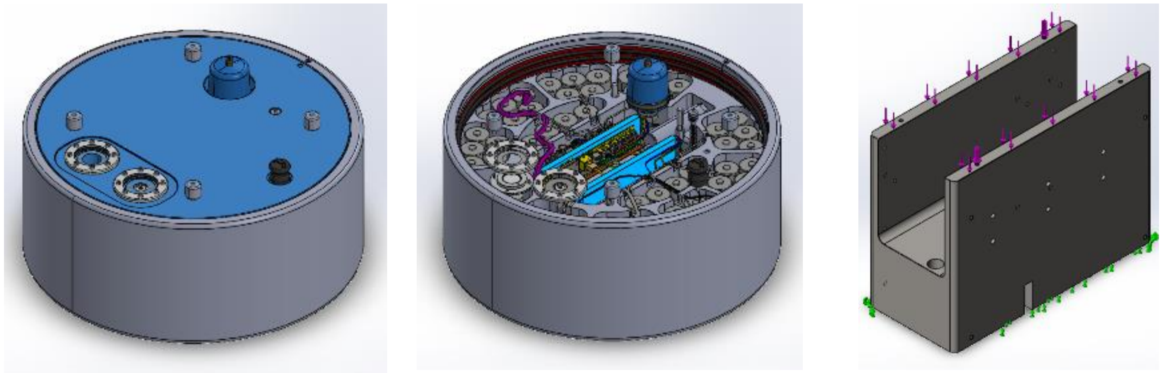
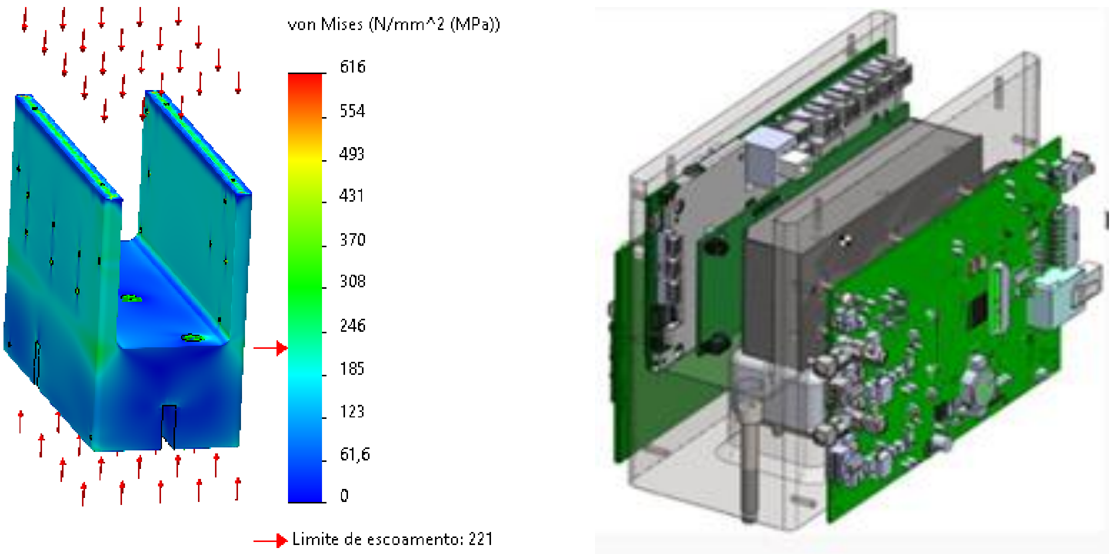
Figure 1. (A): node aluminum housing; (B): node open, without the lid; (C): the column, not in scale.



(A) (B) (C)

In the original model, the column is made of AISI P20 tool steel and weighs approximately 6.7 kg. Electronics installed in the surrounding body must not suffer from external forces, nor wet with salt water or be subjected to high pressure. In Figure 2 (A) a von Mises stress analysis is represented. Figure 2 (B) shows a view of the column with part of the node's electronics fixed around it. In this image, the cabling was omitted so that it is possible to better identify the components.

Figure 2. Static load CAE simulation showing the von Mises stress distribution (A) and the column with the attached electronics around it (B).



(A) (B)

During the assembly of the first prototypes, the column showed disadvantages in terms of fixing and organizing the electronic boards and connecting cables. Hand tools were difficult to handle to access screws and holes locations. Also, components and cables were too tight inside the node making it difficult to set. Additionally, it could lead to broken cables after assembling and sending nodes to the field.

Therefore, thinking about the next prototypes to be built, it was proposed to change the machined part in steel to a part designed following the principles of additive manufacturing. Main goal was to reduce volume of the component “central column” for

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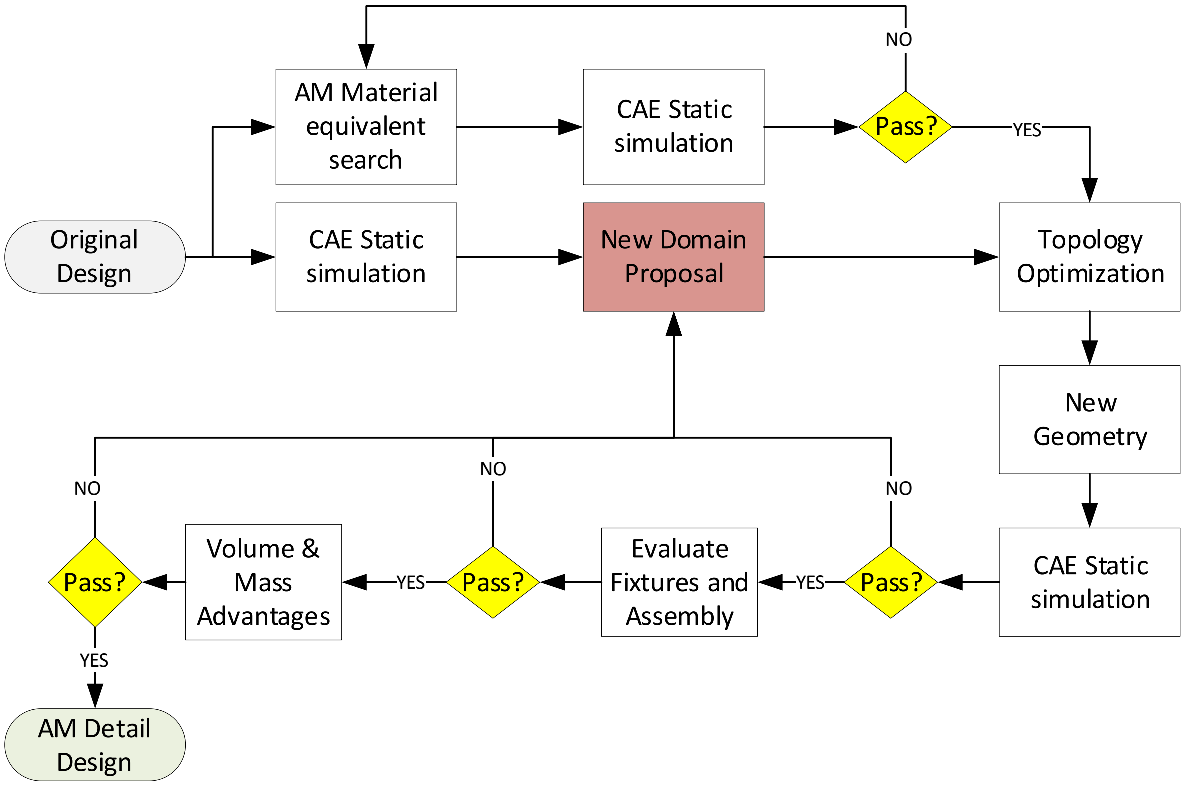
easier assembly. Secondary goal was to reduce the weight of the component. The methodology for carrying out this study is presented next.

2. METHODOLOGY

The proposed methodology for designing the seismic node column is shown in Figure 3. The process starts from the original design, where this is analyzed from the point of view of what are the maximum deformations and displacements allowed for the design. Next, it was necessary to identify materials with similar or superior mechanical properties used in AM manufacturing processes. Selected materials were reapplied in static simulation using original design. In this way, it was possible to consider or discard materials that could be used for the optimized design. In parallel, new domains were proposed as input for topological optimization analysis. These domains consider the spaces in which the topology software must hold material or which are spaces destined for electronic components.

Figure 3. Methodology working flow for design the node column by Additive Manufacturing.



After generating a new geometry by the topological analysis, a second validation CAE analysis was performed with the failure criteria of the original design. Topological analysis is a CAE method where the material is removed where it is not necessary. This leads to organic and optimized designs [3,4]. Afterwards, an analysis of the assembly and fixation of the components was carried out and whether the new project brought advantages in terms of volume and mass reduction. In case the geometry fails in these

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criteria, a new domain proposal with reorganization of the components around it was carried out and the analyzes were redone.

For the structural criterion, the von Mises criterion was adopted from finite element analysis and using the CAE SolidWorks Simulation software to evaluate, through static analysis, the stresses and strains found in each iteration. Topological analyzes were also generated from this same software as well as the CAD design.

2.1 Material properties

The first step to identify the most appropriate material was to seek, among the additive manufacturing technologies, the one that best suits the project's needs. Therefore, the most relevant technology was SLM (Selective Laser Melting) or DMLS (Direct Metal Laser Sintering) [5]. This choice was made for some reasons, the first being the need for the material to have mechanical properties close to those of the original material, since the redesign does not involve the other components of the seismic node. This restriction limits the component's interaction interface and volume.

Another important point was to choose accessible material and technology, that is, easier to be found on the market, for the production of the component. The SLM process has a good range of metal powder manufacturing suppliers. Thus, using data from the literature [2], the SLM presents some materials similar to the AISI P20 material. Therefore, tool steel 1.2909 1219 was selected, available on the SLM Solutions website, one of the SLM technologies provider. The properties of the materials mentioned can be seen in Table 1. These properties were considered for the fabrication with 30 µm thick layers and measured in test specimens built in the Z direction. This direction is considered the most deficient in mechanical properties for the SLM technology.

Table 1. Original AISI P20 tool steel and AM Fe-alloy properties.

Material	Ultimate Stress *	Tensile Stress*	Elongation at rupture*	Elastic Modulus*	Density
	MPa	*MPa*	*%*	*GPa*	*g/cm³*
AISI P20 (original)	400	220	20	205	7,85
Fe-alloy 1.2909 1219	1190	999	10	181	8,00

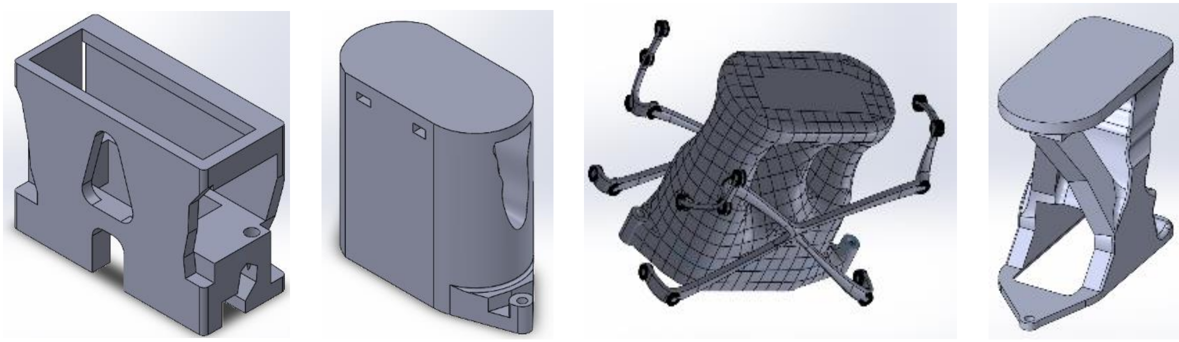
** Properties in the “weakest” direction (Z build axis).*

3. RESULTS AND DISCUSSION

From the proposed methodology, many concepts were generated. Each concept initially departed from the spatial rearrangement of the electronics to be attached to the column of the seismic node. It is noteworthy that, some cables and have specific direction to limited radius of curvature. As an example, sensor cables attached to the housing and fiber optic cables.

For each new domain proposal, topological analyzes were performed, with deformation minimization and mass reduction (i.e. volume) targets. After successive rounds of remodeling and static simulations, different concepts were generated, each based on different ways of attaching electronics to them. Figure 4 presents some of the concepts generated exploring new ways to organize electronic components.

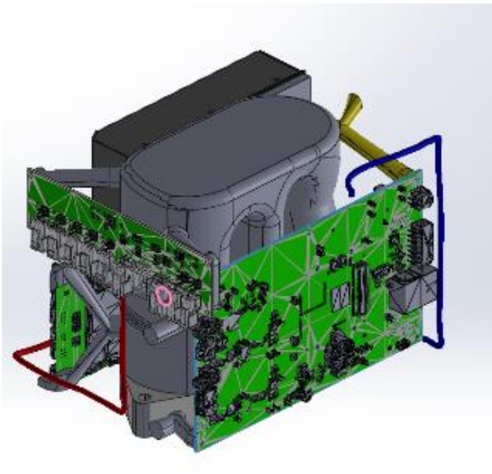
Figure 4. Different AM design alternatives generated.



(A) (B) (C) (D)

The concept in Figure 4 (A) is based on the volume of the original design and did not show large gains in assembly, volume or mass. The concept in Figure 4 (B) is hollow inside and has not yet secured the components well. The model in Figure 4 (D), despite its smaller volume, does not facilitate the assembly of components, especially the laser module. The arms in the concept of Figure 4 (C) serve to screw and secure the electronics, but they could be problematic for the transportation of the nodes (too flexible for low frequencies). Figure 5 presents how the electronics should be placed around this concept.

Figure 5. One of the column concepts assembled with electronics.



After further iterations, a more optimized concept with a deformation less than 0.5 mm was designed. Iterations were developed applying good modeling practices in order to reduce stress concentrators, discontinuities in the mesh, as well as the re-adaptation to the housing base. Interference with other components was evaluated to avoid assembly problems. After the topological optimization, stress reduction features were applied such as fillets for load distribution and stress relief and smoothing surfaces transitions. The generated geometry was able to withstand the requested loads and has a mass of 2188 g. Figure 6 presents the von Mises static analysis of the concept.

Figure 6. Final column concept under von Mises stress failure criteria.

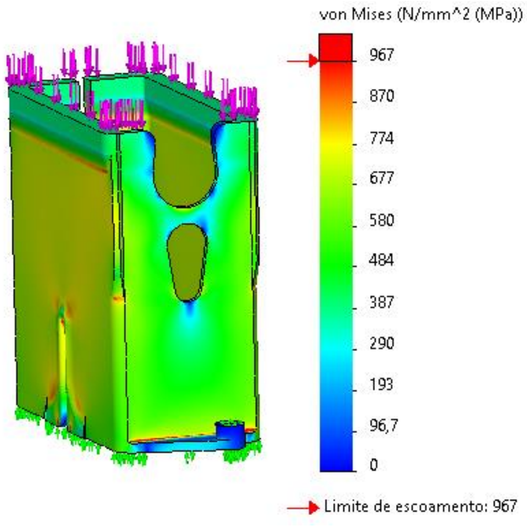


Table 2 compares the original design and the final AM design concept obtained for the seismic node column.

Table 2. Comparison between the original design and the final AM design.

Characteristic	CNC Milled	Final AM Design
Mass (kg)	6,25	2,20
Volume (mm^3)	800.000	273.546
Safety Factor (von Mises)	< 1,3	> 2
Cost (US$)	~400	~4100

4. CONCLUSIONS

Designing an AM component is a challenging task. Despite the design freedom provided by the AM processes, the requirements of the component context proved to be difficult to achieve. There were necessary more than seven concepts to achieve a better design.

Despite the performance in safety factor, displacement and volume reduction, is important to notice that the AM component is 10 times fold more expensive to produce than the original milled version. Nevertheless, the final geometry designed considering the AM freedom in friendly to be made by milling too. It is also possible to make production costs on metallic additive manufacturing cheaper by increasing the number of parts made simultaneously. Nevertheless, as previously commented, this design works for milling and additive manufacturing.

Next step is to 3D print this new concept in plastic for testing the assembly before milling of even 3D printing the new design metallic version.

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5. REFERENCES

[1] ACMA STAFF. **Pros and Cons os Additive Manufacturing**. Available: http://compositesmanufacturingmagazine.com/2014/10/pros-cons-additive-manufacturing/. Last access: 13 jan. 2021

[2] WOHLERS, Terry et al. **Wohlers Report 2020: 3D Printing and Additive Manufacturing Global State of the Industry**. Fort Collins: Wohlers Associates, Inc, 2020.

[3] CAROLO, Lucas. **What Is Topology Optimization? – Simply Explained**. Available: https://all3dp.com/2/topology-optimization-simply-explained/. Last access: 14 jan. 2021.

[4] WECK, Olivier de; KIM, Il Yong. **Design Optimization: structural design optimization.** [S.I]: Massachusetts Institute of Technology, 2004. 58 slides, color. Available: http://web.mit.edu/16.810/www/16.810_L8_Optimization.pdf. Last Access: 11 jan. 2021.

[5] THOMAS, Daniel. **The Development of Design Rules for Selective Laser Melting**. Ph.D. Thesis; University of Wales Institute, Cardiff. 2019.