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Research Article

Design Approaches on Inner Bodies of Gears with Methods Topology Optimization and Lattice Structures

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Abstract

Gears have wide range application areas in various industries which no matter they are small-scaled or large-scaled. As a part of their design, gears inner bodies are full filled with their solid material and significantly increase the weight of systems which they used in. If the weight of gears' body mass can be decrease during their design process, the mechanical properties that expected from the systems can be achieved with the minimum cost of material via additive manufacturing comparing to the traditional manufacturing processes. First ideas which comes to mind presents two choices for the way should follow. This study focused on design optimization of material layout rather than material selection. Generative design technic also known as topology optimization can create new designs via mathematical methods that optimize material layouts within a specific design space. Absolute geometry is depending on various parameters such as given set of loads, boundary conditions and constraints. Alternatively, lattice structures are designs which inspired from bio-entities based on repeating unit cells. As a result of static analysis of a helical gear' s uniform lattice structure, output parameters have been used for varying unit cells' beam thickness and optimize lattice design. End of this study which used nTopology as engineering software for whole implicit design and analysis process, the analysis of generative designed geometry and pattern of lattice structure gave different results. These outputs compared on point of weight savings.

Keywords: Helical Gears, Static Analysis, Topology Optimization, Lattice Structures, nTopology.

Topoloji Optimizasyonu ve Kafes Yapıları Yöntemleriyle Dişlilerin İç Gövdelerinde Tasarım Yaklaşımları

Öz

Dişliler, küçük ölçekli veya büyük ölçekli olsun çeşitli endüstrilerde, geniş uygulama alanlarına sahiptir. Tasarımlarının bir parçası olarak dişlilerin iç gövdeleri katı malzeme ile doludur ve kullanıldığı sistemlerin ağırlığını önemli ölçüde arttırır. Dişlilerin gövde kütlelerinin ağırlıkları tasarım sürecinde azaltılabilirse, geleneksel üretim süreçlerine göre eklemeli imalat ile sistemlerden beklenen

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mekanik özelliklere minimum malzeme maliyeti ile ulaşılabilir. Akla gelen ilk fikirler, izlenmesi gereken yol için iki seçenek sunar. Bu çalışma malzeme seçiminden ziyade, malzeme yerleşiminin tasarımı için optimizasyona odaklanmıştır. Topoloji optimizasyonu olarak da bilinen üretken tasarım tekniği, belirli bir tasarım alanı içindeki malzeme yerleşimlerini optimize eden matematiksel yöntemlerle, yeni tasarımlar oluşturabilir. Mutlak geometri verilen yükler, sınır koşulları ve kısıtlamalar gibi çeşitli parametrelere bağlıdır. Alternatif olarak kafes yapıları, tekrar eden birim hücrelere dayanan ve biyo-varlıklardan ilham alan tasarımlardır. Helisel bir dişlinin iç gövdesine uygulanan uniform kafes yapısının statik analizinin bir sonucu olarak, birim hücrelerin kiriş kalınlığını değiştirmek ve kafes tasarımını optimize etmek için static analizin çıkış parametreleri kullanılmıştır. Tüm tasarım ve analiz süreci için mühendislik yazılımı olarak nTopology'nin kullanıldığı bu çalışmanın sonunda, generatif tasarımlı geometri ve kafes yapı deseninin analizi farklı sonuçlar vermiştir. Bu analiz çıktıları ağırlık tasarrufu açısından karşılaştırılmıştır.

Anahtar Kelimeler: Helis dişli, Statik analiz, Topoloji optimizasyonu, Kafes yapılar, nTopology.

1. Introduction

For decades, traditional manufacturing techniques as proven methods have been constantly preferred for mass production of industrial parts. However, additive manufacturing has robust capabilities of production of lightweighted parts which has high-complexity porous geometry its inside that could not seen from outside of the part how its inner structure.

As hardware, software and 3d printers evolve, it is possible to develop innovative parts that could not be produced before with traditional manufacturing methods. Especially thanks to the software, the development processes can be completed in less time. On the other hand, with nTopology, you can solve the hardest advanced manufacturing and engineering problems, generate unique high-performance parts, share, and reuse your workflows with your team, and more [1].

Also gears have wide range application areas in various industries which no matter they are small-scaled or large-scaled. As a part of their design, gears inner bodies are full filled with their solid material and significantly increase the weight of systems which they used in [2]. If the weight of gears' body mass can be decrease during their design process, the mechanical properties that expected from the systems can be achieved with the minimum cost of material via additive manufacturing comparing to the traditional manufacturing processes [3].

First ideas which comes to mind presents two choices for the way should follow. This study focused on design optimization of material layout rather than material selection. Generative design technic also known as topology optimization can create new designs via mathematical methods that optimize material layouts within a specific design space. Absolute geometry is depending on various parameters such as given set of loads, boundary conditions and constraints [4].

Alternatively, lattice structures are designs which inspired from bio-entities based on repeating unit cells [5]. As a result of static analysis of a helical gear' s uniform lattice structure, output parameters have been used for varying unit cells' beam thickness and optimize lattice design.

End of this study which used nTopology as engineering software for whole implicit design and analysis process, the analysis of generative designed geometry and pattern of lattice structure gave different results. These outputs compared on point of weight savings.

2. Material and Method

2.1. Implicit Modelling and Meshing

nTopology software has blocks based on functions which accepts appropriate inputs. As a result of calculations, blocks also can give outputs that can be suitable for another block's input arguments. This feature enhances the software' s design and analysis capabilities and this study has benefit from its various features. One of them is static analysis result outputs used for changing the thicknesses of lattice structure beams. Thus, instead of the periodic structure's uniform thickness, there are variable thicknesses where it's needed. nTopology blocks can handle various requirements such as import CAD part, convert to implicit body from CAD body, latticing, varying thicknesses with analysis outputs. To do that, a workflow that special to this study's purposes is necessary as a combination of blocks, inputs, and re-used outputs. Figure 1 shows workflow and how blocks look like.

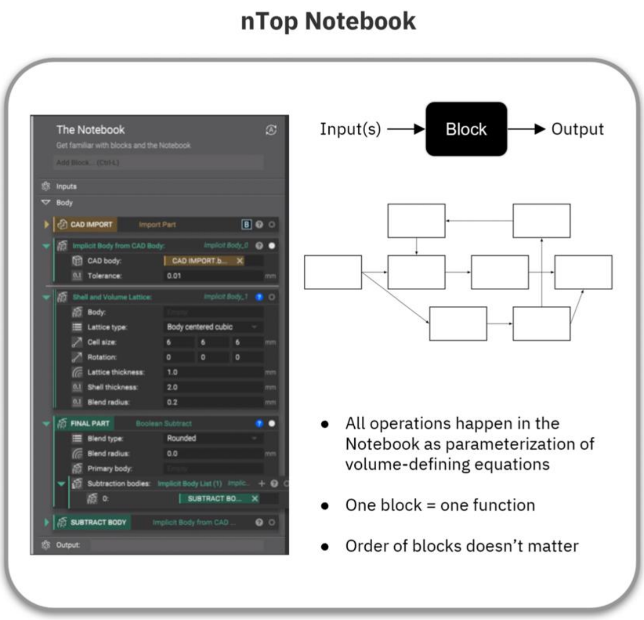

Fig. 1 Workflow and blocks (ntopology.com)

In order to re-design helical gear's full-filled inner body as a lattice structure, previously designed and imported CAD data of the helical gear must be converted to an implicit body. CAD data of gear has some design parameters as shown in the Table 1 [6].

Table 1. Gear Design Parameters

Parameters	Values
Gear Module	3
No. of Teeth	30
Addendum	1*m
Dedendum	1.25*m
Width	22.5

Figure 2 shows the parts of the gear CAD data. Inner body is the necessary part for latticing and topology optimization. The center part is where displacement restraint boundary conditions applied and the outer one is where loads applied.

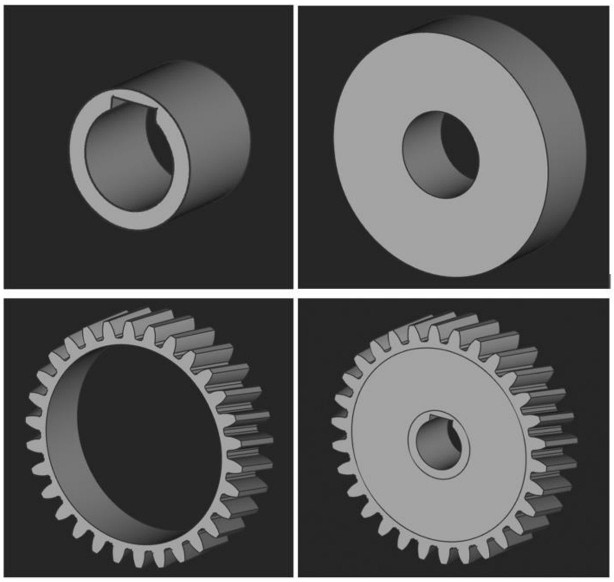

Fig. 2 Parts of CAD Data

To create a lattice structure from implicit body, using of “Volume Lattice” block is essential. Material layouts and volume ratios can be affected depending on selection of “Unit Cell” parameter. Figure 3 shows various graph type unit cells except triply periodic minimal surface ones. Also, table 2 shows that “Octet” unit cell type presents highest weight saving for the biggest unit cell size rather than others.

Table 2. Comparison of Unit Cells

Unit Cell	Cell Size	Ratio
Simple Cube	[4, 4, 4] mm	32.4%
BCC	[5, 5, 5] mm	31%
FCC	[5, 5, 5] mm	28.1%
Diamond	[5, 5, 5] mm	30.7%
Fluorite	[8, 8, 8] mm	32.3%
Octet	[10, 10, 10] mm	32.8%
Truncated cube	[4, 4, 4] mm	29.2%

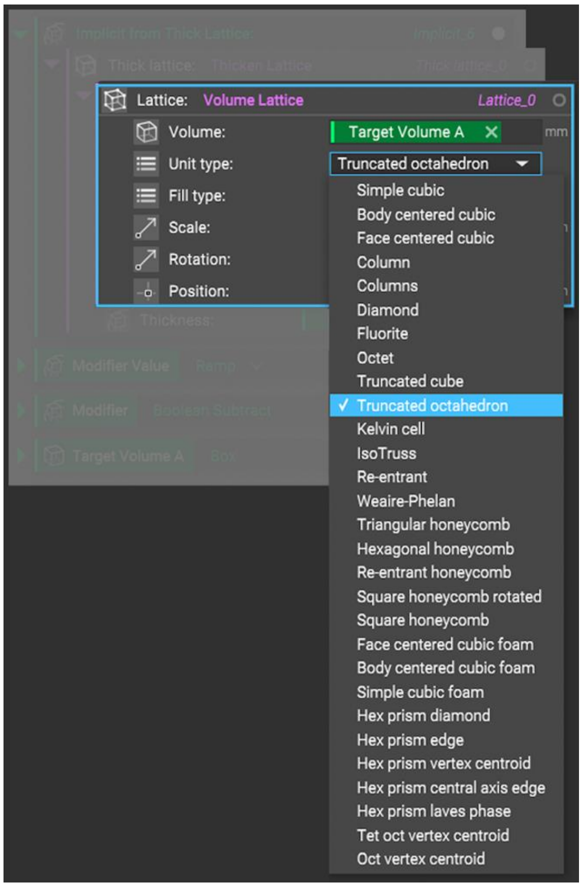

Fig. 3 Various Unit Cells

After settings of input parameters, Figure 4 shows the lattice structure which has uniform beam thickness.

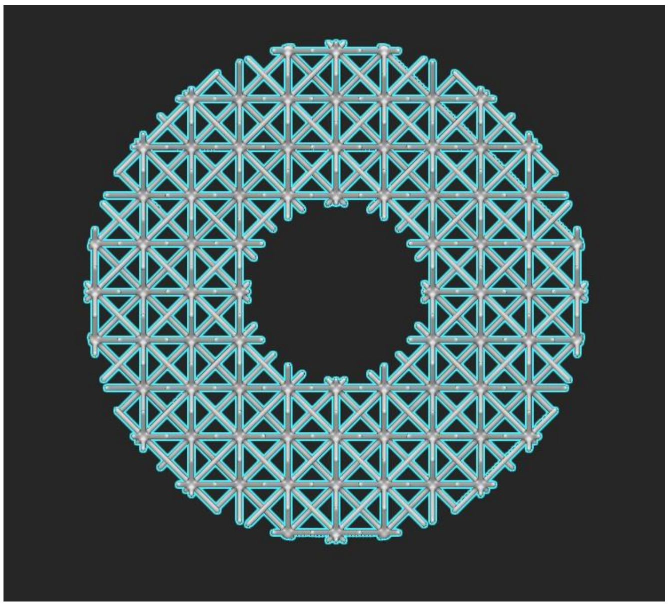

Fig. 4 Lattice structure with uniform thickness

The lattice structure should be merged with other implicit bodies for creating an instance of single implicit body, thus, as a next step, the part can be ready for meshing via the block "Mesh from Implicit Body". To do that, “Boolean Union” block accepts multiple implicit bodies as inputs which you want to merged ones, also this block presents a radius option which you can select its value to create rounded intersection areas.

"Mesh from Implicit Body" block is first step of whole meshing process. Tolerance setting can affect quality and meshing time. Decreasing of tolerance value can improve the quality and you can observe that captured body curvatures clearly without black lines via uncheck the wireframe option in the block's properties tab. Adjustment of optimum value may require multiple attempts.

Second step of meshing goes on "Remesh Surface" block. This block tries to create equal surface mesh elements. Mesh metrics should be checked. Mesh metrics are "closed, oriented, manifold and self-intersecting". In sequence except last one, you should see their values as bool type of "true". Self-intersecting should be "false". Otherwise, you will receive a warning from the software.

Third step is using the "Volume Mesh" block that creates a solid mesh with tetrahedral elements. As output data, clean surface meshes can be an input data of the "Volume Mesh" block. Equality of "Edge length" values is recommended. So, volume mesh elements can be created easily derived from surface mesh elements' edge sizes. Also, last step is using the "FE Volume Mesh" Block that defines placement of nodal elements in the solid mesh elements. Figure 5 shows the order of meshing process and Figure 6 shows the parameters of these mesh blocks. Figure 7 shows the gear which has FE volume mesh.

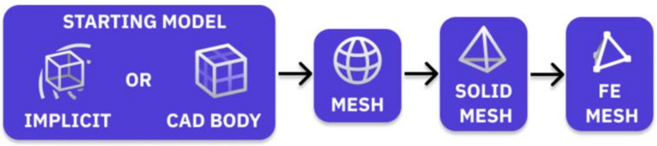

Fig. 5 Order of meshing process (ntopology.com)

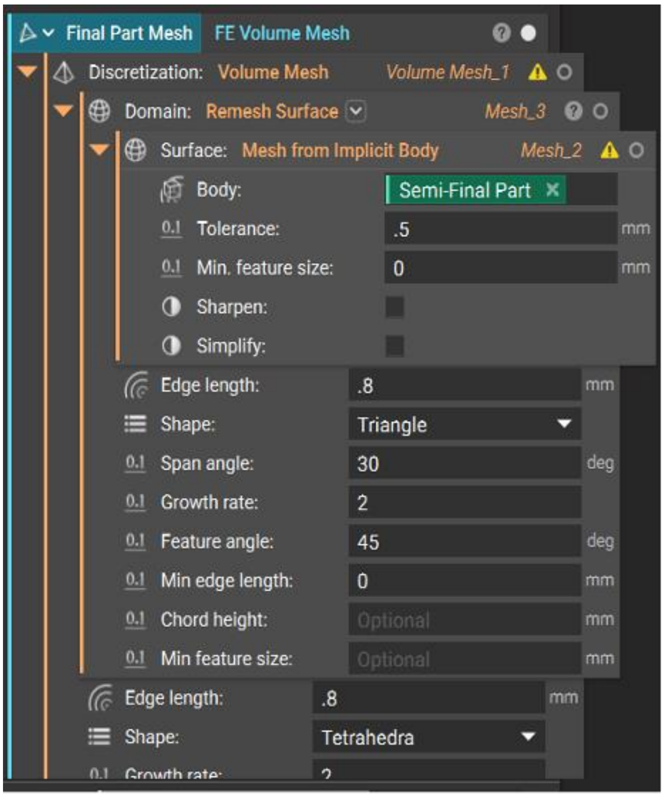

Fig. 6 Parameters of mesh blocks

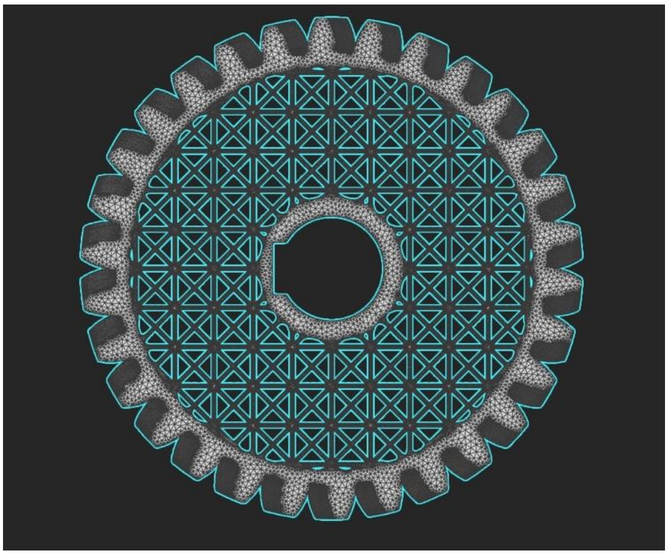

Fig. 7 Gear which has finite element volume mesh

2.2. Static Analysis Setup

Before running a simulation of static analysis, "FE Model" block parameters and "Load Case" should be set up. To create a "FE Component", material and mesh components can bring together. In this study, selected material AI6061-T6 is pre-defined in the software's material library. Also, 250N distributed force applied to the helical gear's teeth surface. Figure 8 and Figure 9 shows all steps of the analysis set up.

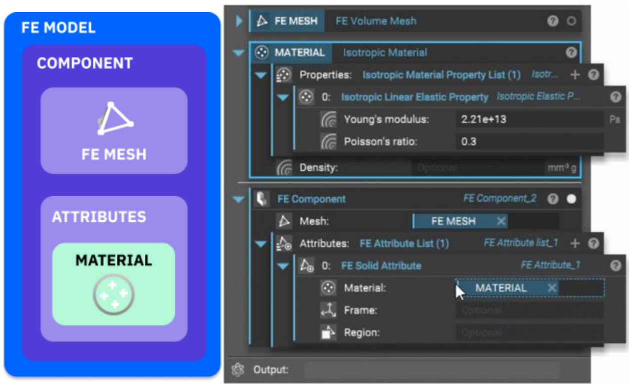

Fig. 8 Creating a FE component before static analysis

Fig. 9 Static analysis case set up

2.3. Field-driven design and Re-construction

Static analysis block's output property list gives the Von Mises data. As an advantage of implicit modelling technics, this data can be used as an input data to create point map with the related block. Also, the point map block's output is an input to create "Fields". "Ramp" block gives the capability of Field-driven design that can change uniform thickness of lattice. Ramp block uses the "Field" input. Figure 10 shows the Von Mises data and Figure 11 shows the essential block named "Ramp" for "Field-driven" design.

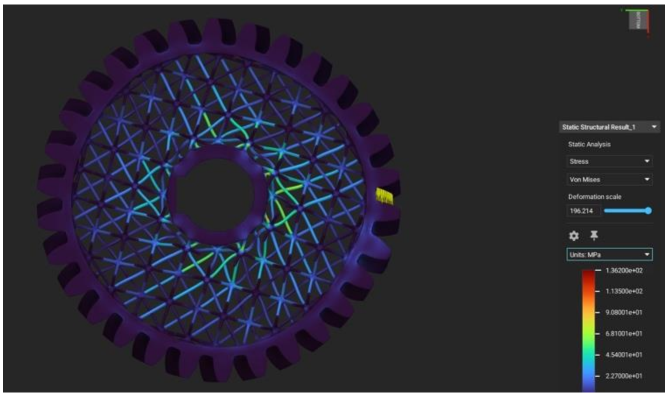

Fig. 10 Von Mises data for "Field-driven" re-construction process

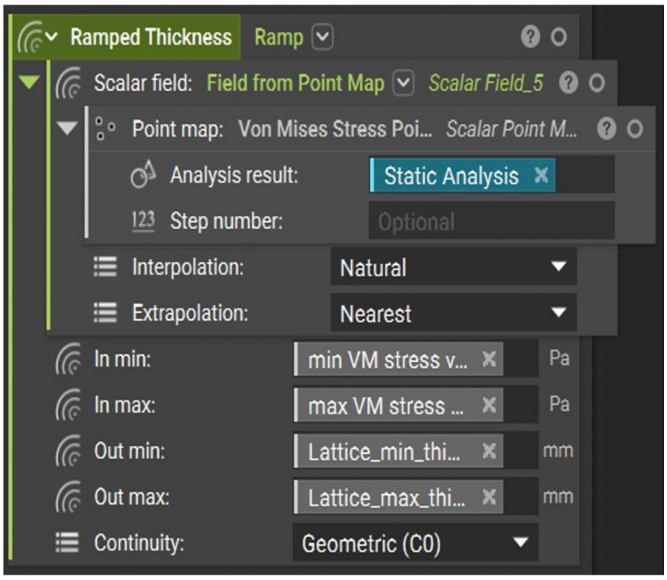

Fig. 11 Point map, scalar fields, and "Ramp" block

Ramp block's one parameter limits the maximum thickness of beams. Engineers can set automatically minimum and maximum diameter of beams based on Von Mises data range. "Field-driven" design technic improves lattice structures material layout and optimizes its periodic lattice design which has uniform thickness depending on analysis. Figure 12 shows "Fields" and Figure 13 shows re-constructed design.

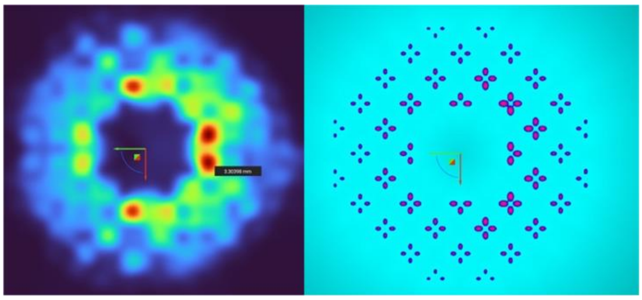

Fig. 12 Field sections based on data and geometry

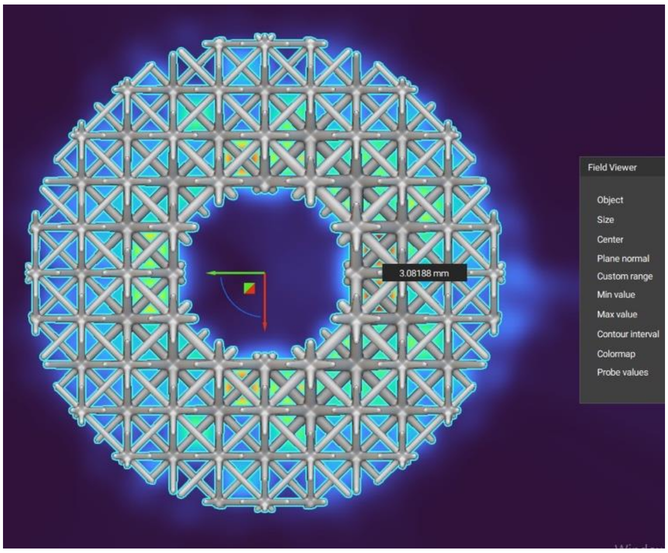

Fig. 13 Re-constructed design

To design the helical gear's inner body geometry via topology optimization, majority of design steps similar such as converting cad body to implicit body, meshing and FE Model. "Structural Compliance Response" block, "Optimization Objective" block, "Optimization Constraint List" block, "Topology Optimization" block, and "Smoothen Body" blocks are different blocks that included in topology optimization workflow comparing to the lattice design workflow. Figure 14 shows topology optimization of gear's inner body.

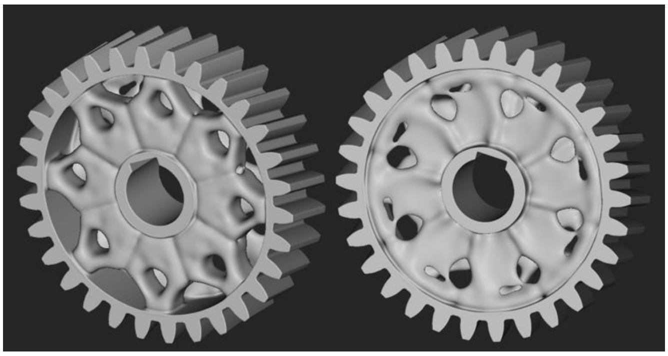

Fig. 14 Topology optimization of gear's inner body.

3. Results and Discussion

Approximately, initial analysis results of lattice structure showed 137 MPa Von Mises value. Field-driven design improved the result and decrease it to 49 MPa. In addition, weight saving is just under %60. Figure 15 shows improved lattice design analysis results.

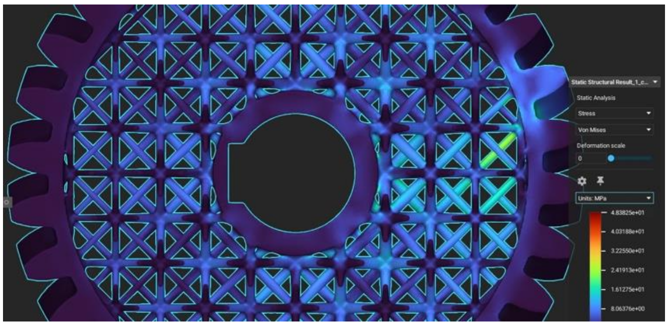

Fig. 15 New lattice design static analysis results

Figure 16 shows the topology optimization analysis results comparing to the initial cad geometry which has full filled inner body of helical gear.

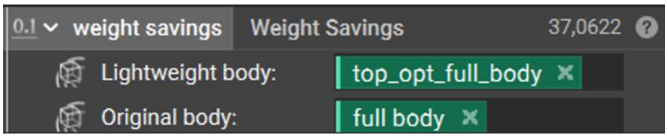

Fig. 16 Weight savings of topology optimization

According to the initial lattice design and load scenario, thin beams caused weak lattice structure and decrease structure's mechanical property. The helical gear's teeth construction looks preserved and more robust although "Deformation scale" that is exaggerated graphical presentation was increased. Figure 17 shows weakness of initial lattice. Figure 18 shows robust new lattice design, however weakness of shell thickness of outer body.

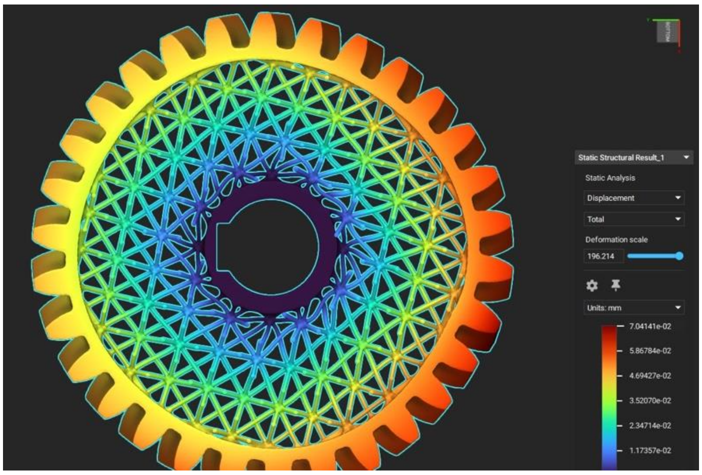

Fig. 17 Weakness of initial lattice design

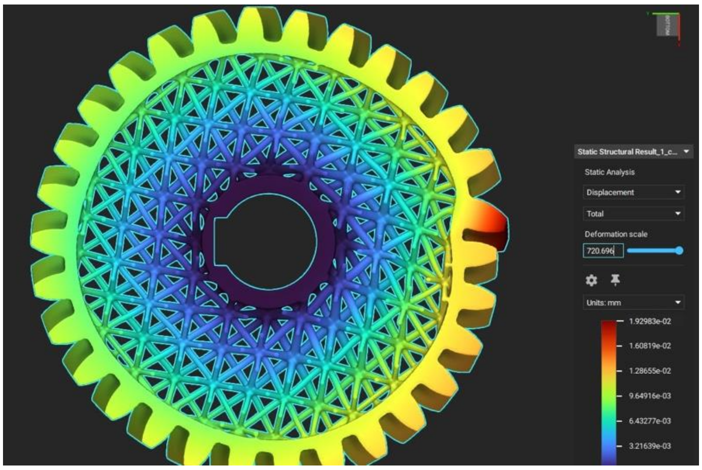

Fig. 18 Weakness of shell thickness of outer body

4. Conclusions and Recommendations

Full filled parts such as brackets, gears should be optimized for weight savings and decrease material costs of additive manufacturing. Field-driven design provides new improved designs that derived from its initial analysis data.

5. Acknowledge

This research was supported with academic licenced software by nTopology Inc. We are grateful for the opportunities that Kutahya Dumlupinar University offers. We would also like to show our gratitude to the Prof. Dr. Ramazan Kose (Kutahya Dumlupinar University) for sharing their pearls of wisdom with us during this research, and we thank 2 reviewers for acceptance of this paper.

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