

DEVELOPING FUTURE GEAR BY OPTIMISED INTERNAL GEOMETRY NUR BALQISH BINTI MUSLIM Jeigen und August August MELAKA

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Faculty of Mechanical and Manufacturing Engineering Technology



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Bachelor of Mechanical Engineering Technology (Maintenance Technology) with Honours

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DEVELOPING FUTURE GEAR BY OPTIMISED INTERNAL GEOMETRY

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

DECLARATION

I declare that this Choose an item. entitled "Developing Future Gear By Optimised Internal Geometry" is the result of my research except as cited in the references. Choose an item. has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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APPROVAL

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DEDICATION

This project is dedicated works to my beloved parents, family, and especially to my supervisor Dr. Muhammad Ilman Hakimi Chua Bin Abdullah, whose prayers, offered affection enabled love and support which always acted as a catalyst. Thank you so much for giving me strength to finish my Final Year Project. They have given me the motivation and discipline to take on any assignment with passion and commitment, no matter how difficult. Last but not least, thank you to all of my friends who have supported me throughout this process. It would not have been able to complete this task without their assistance.



ABSTRACT

The purpose of this research is to study the design of optimised gear based on the existing gear in the online market. There are many types of gear that exist, made from different materials. Each type of gear has unique properties such as bending stress, strength, wear, and so on. The material has been used in appropriate conditions as needed. For this research project, the simplest gear has been chosen, which is spur gear from the online store. One of the gear models has been chosen and drawn in CATIA V5R21, which is one of the CAD software. Next, the model of the gear has been analysed and drawn in CATIA V5R21, followed by the dimension that has been given in the catalogue for the customer. Then, in CATIA V5R21 too, simple simulations have been analysed in the software for analysing static analysis and dynamic analysis. From the drawing, the replica of the gear is produced the same as the real one in the online market using 3D printing, which is an SLS machine. The gear replica is made from PA12 NYLON material, while the original gear that has been purchased is made from brass material. Both of these pieces of equipment are used to investigate the wear of each piece of equipment. The study used the disc experiment method. The result of the experiment and the data recorded are presented in this thesis. The result of the experiment was to differentiate between the two types of gear.

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ABSTRAK

Kertas kajian ini bertujuan untuk mengkaji tentang reka bentuk gear yang optimum berdasarkan gear yang telah berada dipasaran. Terdapat pelbagai jenis gear yang dibuat dengan pebagai jenis bahan. Setiap bahan yang digunakan mempunyai ciri-ciri yang berbeza seperti tekanan lenturan, kekuatan bahan, keausan dan sebagainya mengikut kesesuaian dan keadaan yang diperlukan. Gear juga mempunya pelbagai jenis bentuk dan ukuran. Untuk kertas kajian ini, gear tunjang iaitu gear yang paling ringkas telah dipilih daripada laman web yang berada ditalian. Model gear yang telah dipilih kemudian dilukis semula salah satu daripada software CAD iaitu CATIA V5R21. Reka bentuk tersebut telah dianalisis dan dilukis didalam CATIA V5R21 mengikut dimensi yang diberikan didalam katalog yang diberikan untuk para pelanggan. Seterusnya, simulasi ringkas telah dianalisis didalam software yang sama iaitu CATIA V5R21 untuk analisis statik dan analisis dinamik. Melalui lukisan semula reka bentuk tersebut, replika gear telah dihasilkan menggunakan 3-D print iaitu SLS. Replika gear yang diperbuat daripada bahan PA12 NYLON berserta gear original yang telah dipurchase yang diperbuat dari bahan BRASS digunakan untuk mengkaji keausan bahan. Kajian tersebut menggunakan kaedah eksperimen pin on disc. Keputusan eksperimen berserta data yang dihasilkan telah dibentangkan didalam kertas kajian ini. Keputusan kajian daripada eksperimen tersebut adalah berkaitan untuk membanding beza antara kedua gear tersebut.

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CHAPTER 1

INTRODUCTION

1.0 Introduction

A gear is one of the machine components that is used to transmit mechanical power from one shaft to another shaft, whose teeth are cut into cylindrical or cone-shaped patterns with equal spacing. The gear is the most crucial part of the machine that affects the efficiency of the machine's work. A pair of gears is used to transmit rotation and force. The optimal design of the gear helps to improve work performance in the machine and makes sure it is well functioning.

Gears are widely used in power and motion transfer work under differing loads and velocities. These gears are preferred and successfully used in machinery, the aerospace industry, textile machinery, and other industries. Gearing is an essential component of machinery, and gear collision is the primary cause of machinery failure. The spur gear is the simplest form of gear to make and is widely used to shift rotary motion between parallel shafts. Spur gears are exposed to a variety of stresses in operation, but two types of stresses, bending stress and contact stress, are critical from a design standpoint. In developing optimised gear, there are a few characteristics that need to be fulfilled, which are optimising the gear geometry, highefficiency performance, and low noise when the machine is working. The geometry influences the gear's manufacturability and working parameters, which define the gear's potential use region.

All gears and most industrial rotating machinery require some gearing to allow the work to be done, and more work can be done in excess. The rapid transition of heavy industries such as automobile manufacturing and office automation tools will necessitate a refined application of gear technology. Furthermore, due to their high degree of reliability and compactness, gears may predominate as the most effective means of transmitting power in future machines. The growing demand for quiet power transmission in machines, vehicles, elevators, and generators has increased the demand for a more precise analysis of gear system characteristics. Higher reliability and lighter weight gears are required in the automobile industry, the largest manufacturer of gears, as lighter automobiles continue to be in demand.

Straight-cut gears are the simplest type of gearing. They have cylinders or discs as components parallel to the axis of rotation stresses are defined by the primary and secondary designations of the gears, and in complex gear trains, the parameters greatly influence the design. As a result, The American Gear Manufacturing Association, AGMA established the current standard for spur gear design. Two horizontal sprockets rotating at the same rate (and they are alike in all other respects) can be imagined to have a third at the interface provided the sole end of one gear can be seen when they roll slowly. The biggest problem with these rotating drums is the risk of slipping at the rotating joint, but this is mitigated by adding teeth to the rolling drums. Designed internal gear racks with heavy load ratios for the power transmission system are extremely heavy in use. Methods alike rely on analysis to convey strength and to offer data; in particular, they call for analysis to offer both "bending" and "stress" information and greater contact. The results of this variable are applied where the teeth meet the bushing, the interface of gears, which is observed during gear contact checking.

1.2 Problem Statement

Gears are used in situations where a constant velocity ratio is desired, and they have a low impact on the shafts on which they are mounted. For power transmission, a minimum of two gears are needed, one of which is smaller in diameter than the other device and is known as a pinion, and the other as a gear. As rotational speed is applied between these two touching gears, the axes of rotation of the two gears vary from one another. For this project, spur gear was chosen for fabrication using a 3D printer. Spur gears are used where all shafts on which the gears are placed must be parallel and the teeth of these gears are straight and parallel to the axis of the shafts. Because of their compact structure and nature, these gears are simple to make. By established spur gear using plastic, it gives an alternative to traditional metal gears for a wide range of industrial applications. Plastic gears have evolved from low weight, precise motion transmission to more advanced power transmission applications. This research project employs 3D printing technology to create spur gears with precise geometry. Custom designs may be produced in a short amount of time without using the traditional production process 3D printing technology can be used.

1.3 Objective

The objective of this project is stated as below;

- 1. To design and analyze future gear with optimizing geometry.
- 2. To fabricate the designed gear using 3D SLS machine.
- 3. To test gear compare to current gear by simulation.

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1.4 Scope

The scope of this project is stated as below;

- 1. Investigating the optimum gear design that is commonly used in the industry by analyzing the geometry.
- 2. Fabricating the gear with analyzed the optimized geometry using Catia and 3D printing.
- 3. Testing the performance of the gear and analyzing the designed product in the spec of structure and performance compare to conventional gear by SIMSOLID simulation.

CHAPTER 2

LITERATURE REVIEW

2.1 Gears

Gear is the component in the machine that has transmission power. The gears range from small-scale, which is from millimetre dimension installations, to large, powerful turbine gears of several metres in diameter. Gears can deliver very high angular or linear precision position transmissions, such as in-service mechanisms and military equipment. Gears can link power and movement between shafts that have parallel, twisted, or skewed axes. Gear designs are standardised according to size and shape for broad interchangeability. Gear has been used for more than 3000 years. It is very useful for every machine operation and has been used from generation to generation. Gears range in size from micrometres to 20m in diameter. From lightweight plastics to ultrahigh-strength heat-treated steel, materials are available (Davis & Associates, 2005). Each piece of gear has a unique characteristic that allows it to be used in the appropriate situation and according to the requirements. Rotation and power transmission between two parallel shafts If rotational transmission occurs at a constant ratio, which equals a constant RPM input, a constant output in RPM will be required (Stadtfeld, n.d.). The equationbased gearing law:

 IN_1XR_1i . $I = IN_2XR_2I = constant$

N1 normal vector flank point 1

R1 radius vector tooth flank point 1

N2 normal vector flank point 2

R2 radius vector tooth flank point 2

i transmission ratio

2.1.1 Types of Gear

There are a lot of types of gear in this world. Every type of gear has its function. To achieve necessary force transmission in mechanical designs, it is necessary to accurately understand the differences between gear types. Even after deciding on a general type, dimensions and other factors must be considered. Gears of various shapes are available depending on the machine's requirements. Every piece of equipment has benefits and drawbacks that can be used in various conditions and situations.



Figure 2.1 Spur Gear (Petry-Johnson et al., 2008)

The spur gear is the simplest gear among the other types of gear. They are made up of a cylinder or disc with teeth that protrude radially. The edge of each tooth is straight and aligned parallel to the axis of rotation, despite the teeth not being straight-sided (but usually of a special form to achieve a constant drive ratio, primarily involute but less commonly cycloidal). Only when these gears are mounted on parallel shafts will they mesh properly. The tooth loads do not produce any axial thrust. Spur gears perform well at moderate speeds but are noisy at higher speeds.



Figure 2.2 Helical Gear (Davis & Associates, 2005)

The shape of helical gear is almost the look like spur gear the cut of the teeth has an angle while the spur gear is straight to the center of the gear. Helical gears connecting parallel shafts will run more smoothly and quietly than spur gears, especially when the helix angle is large enough to ensure smooth operation that there is continuous contact from one tooth to the next (Niijjaawan & Niijjaawan, 2010).



Figure 2.3 Worm gears (Hamid Seyed Sadeghi et al., 2017)

Worm gears are made up of a worm and a gear with shafts that are non-parallel and nonintersecting and are oriented at 90 degrees to each other. The worm resembles a screw with a V-type thread, while the gear resembles a spur gear. Typically, the worm is the driving component, with the worm's thread advancing the gear's teeth. Worm gears are made up of a worm and a gear with shafts that are non-parallel and non-intersecting and are oriented at 90 degrees to each other. The worm resembles a screw with a V-type thread, while the gear resembles a spur gear. Typically, the worm is the driving component, with the worm's thread advancing the gear's teeth (Niijjaawan & Niijjaawan, 2010).



Figure 2.4 Bevel Gears (Davis & Associates, 2005)

Bevel gear is different from other types of gear that exist. Bevel gear The axes of the two shafts intersect in bevel gears, and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are typically mounted on shafts that are 90 degrees apart, but they can also be designed to work at different angles. Bevel gears have a cone-shaped pitch surface. The axes of the two shafts intersect in bevel gears, and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are typically mounted on shafts that are 90 degrees apart, but they can also be designed to work at different angles. Bevel gears, and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are typically mounted on shafts that are 90 degrees apart, but they can also be designed to work at different angles. Bevel gears have a cone-shaped pitch surface (Childs, 2019).

2.1.2 Material in gear

The material of gear is really important to choose depending on the needs. There are a lot of sorts of materials that have been used, such as steel, bronze, plastics, ductile iron, cast iron, brass, and metal. When creating the gear, strength, durability, and other material attributes must be taken into account. While the relevance of these elements varies depending on the project, the key to material selection is finding the perfect mix of physical attributes that meet the project's objectives at the lowest cost. Davis & Associates said among the through-hardening steels in wide use are 1040, 1060, 4140, and 4340. These steels can also be effectively case hardened by induction heating. Among the carburizing steels used in gears, see Table 2.1.

Table 2.1 Recommended steels for various applications and gear types (Davis & Associates,

20	2005)	
Typical industrial application	Gear design type	Typical material choice
Differentials		
Automotive	Hypoid, spiral/straight bevel	4118, 4140, 4027, 4028, 4620, 8620,8625, 8822
Heavy truck Drives	Hypoid, spiral/straight bevel	4817, 4820, 8625, 8822
Industrial	Helical, spur rack and pinion, worm	1045, 1050, 4140, 4142, 4150, 4320, 4340, 4620
Tractor-accessory Engine	Crossed-axis helical, helical	1045, 1144, 4118, 4140
Heavy Truck	Crossed-axis helical, spur, worm	1020, 1117, 4140, 4145, 5140, 8620
Equipment		
Earth moving	Spiral/straight bevel, zerol	1045, 4140, 4150, 4340, 4620, 4820, 8620, 9310
Farming	Face, internal, spiral/straight bevel, spur	4118, 4320, 4817, 4820, 8620, 8822
Mining, Paper/steel Mill	Helical, herringbone, miter, spur, spur rack and pinion	1020, 1045, 4140, 4150, 4320, 4620
Starters		
Automotive	Spur	1045,1050
Transmission		
Automotive	Helical, spur	4027, 4028, 4118, 8620
Heavy Truck	Helical, spur	4027, 4028, 4620, 4817, 5120, 8620, 8622, 9310
Marine	Helical, helical conical, spiral bevel	8620, 8622

Off Highway	Helical, internal, spiral/straight	1118, 5130, 5140, 5150, 8620,
On figliway	bevel, spur	8822, 9310
Tractor	Herringbone, internal, spur	4118, 4140, 8822

Steel is the most typical material in general, although we've worked with all of the material kinds stated above throughout the years. Steel is frequently used because of its winning combination of high strength-to-weight ratio, strong resistance to wear, the ability to improve physical qualities by heat treatment, and competitive cost.

2.1.3 Gear Geometry

Gear geometry shows the important part of the design of the common gear. The shape of teeth in gear must be precise with the geometry specification to make sure it can be functioning well to transmit power in the mechanical system. By gear geometry, it can be knowing the gear is critical for ensuring that gears mesh properly.



Figure 2.5 Basic Geometry of Spur Gear (Gabrijel-Persin, 2013)

The contact point on an involute profile gear tooth starts closer to one gear and goes away from that gear and toward the other as the gear rotates. If it followed the contact point, it would depict a straight line that begins at one gear and finishes near the other. This implies that when the teeth engage, the radius of the contact point expands.



2.1.3.1 Gear Tooth

Figure 2.6 Tooth Gear Geometry

The geometry of the gears tooth is very important to be precise. The depth of gear tooth is determined from the size of the module gear. A method for designing gears with circular tip and dedendum arcs with straight-line flanks is proposed, which involves laying out an isosceles triangle and drawing circular tip and dedendum arcs relative to the base side and base corners of the triangle, the arcs having radii no greater than one-fourth the length of the base. Their Tooth depth is determined from the size of the module (m).

The diameter of the pitch is the effective diameter of contact. The pitch diameter is the average contact distance since the contact diameter is not constant. The top gear tooth touches the lower gear tooth in a pitch diameter when the teeth start to move. Note that at this moment the section of the top gear tooth that touches the under gear tooth is quite fine. The point of contact slides on the thicker section of the top gear tooth when the gear is rotated. It pulls the top gear ahead so that the lower contact diameter is compensated for.

2.2 Design Software

There a lot of design software that can be used for designing and drawing. Design software function or for engineering technical it called as the computer-aided design is specific for technical documentation. CAD is used in the creation, analysis, modification, or optimization of the design. This design software also eases for a design engineer to improve the productivity from the design to communicate through the drawing. A design process comprises functional design, fundamental design, and detailed design. Because a designer should define the functional structure and basic physic mechanisms in the conceptual design of an object, conceptual design is more significant than basic design or detail design (Tomiyama et al., 1993). CAD software for dispute resolution Eco-Design Tool is designed to assist engineers in developing eco-innovative goods, by looking for eco-Design objectives and assessing product environmental performance (H. T. Chang & Chen, 2004).

2.2.1 3-D Drawing

3-D engineering is one of the technologies that very important to the industry and design engineer. 3D drawing is modeling a three-dimensional graphic image for any part of the object. The geometry of the part of the technical drawing is generated first by a 3D CAD system from user-defined views of the geometry. The program creates any spelling, projected, or sectioned view. In the generation of these perspectives, there is no scope for the mistake. The primary error scope is the first or third angle projection parameter, with the corresponding symbol displayed on the technical picture. 3D CAD makes it possible to combine various components to show the result. Before releasing technical drawings for manufacturing, buildings, airplanes, ships, and vehicles will be modeled, constructed and 3D inspected. Manipulating things and producing pictures of things is vital in most applications that involve computing with 3D geometric models. For these processes, the spatial relationships between objects must be determined for each animated frame how they might cross and dislocate each other (Sitharama Iyengar et al., 2005).

2.2.2 CATIA V5R21

CATIA is a programme used to generate objects and modify them. CATIA is also available for design and modeling. Design denotes the creation or modification of a new thing. Drafting means the object's depiction or conception. Creating and converting 2D to 3D implies modeling. Create the model of the equipment with CATIA software (Sreerama, 2019). CATIA is software modeling that is used to generate and modify things. Design features and models are accessible in CATIA. Design means the process through which an existing thing is created or changed (Prasad & Reddy, 2020).



Figure 2.7 Examples of working area in CATIA software (Naprstkova, 2011)

CATIA V5 is the software covering many of the fields now employed, including the design from start to finish, a wide range of scans, simulations and optimizations, drawings, and NC programs for the production itself. The software comprises the design, production, and design of products. It may be implemented and used in a broad range of industries, such as the automotive or aerospace sectors, manufacturing of consumer products, machine tools, and heavy-duty equipment (Naprstkova, 2011).

2.3 SLS Printing

Selective Laser Sintering or we called as SLS is one of the additive manufacturing technique which it used power source of laser to sinter the material in powdered condition. Usually, nylon and polyamide are used as the material. The laser in this SLS aching will automatically focus on the point from the 3D model it had been defined. The powder will be compacted and create a solid structure. 3D printers are a new technological machine that is capable of transforming the digital design into 3D objects and can also produce nearly all things in everyday human existence. They are highly helpful since multiple types of items may be produced, with different materials from one machine. 3D printers are employed in a wide range of sectors, including automotive, aerospace, military, education, health, architects, designers, and consumer items. Additive production, however, leads to environmental emissions from printing (Damanhuri et al., 2019).

2.3.1 Material of 3-D Prints

Nylon is the most typical material for selective laser sintering. Nylon functions as a prototype and end-use production which is highly capable of engineering thermoplastic. Selective laser sintering is used to sinter material such as nylon 11, nylon 12 also known as polyamide 11 (PA11), and polyamide 12 in powder form. Laser is a power source used as a laser (PA12) (Damanhuri et al., 2019). Selective laser sintering for sintering materials such as nylon 11, polyamide 11 (PA11), nylon 12, powdered polyamide 12 is performed. Laser is a laser power supply (PA12). Nylon belongs to the polyamide family and is a synthetic thermoplastic polymer. Nylon 12 is a flexible general use powder to print 3D SLS. It allows a wide variety of applications. Nylon 11 helps to fill the prototype and end-uses gap that demands greater ductility, impact resistance and wear and tear resistance with no fragile failures (*Guide to*

Selective Laser Sintering (SLS) 3D Printing, n.d.). Polyamide 12 (PA12) is the most widely used polymer for both PBF processes because of a broad temperature range between its onset melting temperature (during heating) and its onset crystallization temperature (during cooling).

Table 2.2 SLS Nylon Material Properties (Guide to Selective Laser Sintering (SLS) 3D

	Nylon 12 Powder	Nylon 11 Powder
Ultimate Tensile Strength	50 MPa	49 MPa
Tensile modulus	1850 MPa	1573 MPa
Elongation at Break (X/Y)	11%	40%
Notched IZOD	32 J/m	71 J/m
Heat Deflection Temperature (HDT) @ 0.45MPa	171 °C	182 °C
For anno		
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Printing, n.d.)

2.3.2 Printing



For SLS printing technology used powdered material in creating an object by heat the material layer per layer. From the 3D drawing that has been transferred to the specific, it will give the instruction to the machine which tells where the material will be solidified and get the 3D structure. The powder is then sintered on a platform layer by layer and sticks together to turn into a solid object (Damanhuri et al., 2019).

2.3.3 Finishing

In SLS, the finishing part is the typical practice with several techniques. Standard finishing after a 3D print is removed the unsintered part with compressed air from the surface. This kind of finishing usually is rough and needs to be smoother. For a smoother surface media tumbler is used to polish the Nylon part. This vibro polished techniques finish gives a small effect on the part of dimension and round sharp edges as the result. Next, the quickest technique of

coloring SLS prints is through a coloring procedure. SLS components are good for dyeing because of their porosity. The portion is submerged in a heated bath with a wide variety of colors. Using a colored bath, both inner and outside surfaces are completely covered. Normally, the dye penetrates the component only to the depth of 0.5 mm. The original powder color is exposed to continuing wear to the surface. The most efficient method for finishing hard and brittle material such as this 3D print product is made from nylon is precision grinding (Damanhuri et al., 2019).



CHAPTER 3

METHODOLOGY

3.1 Overview

This research aimed to develop future gear by comparing the existing gear. In this chapter, it needs to be done gradually. The methodology is important to make sure the correct steps to successfully achieve the objectives. This figure illustrates the flow chart diagram for this research.



Figure 3.1 Flow Chart

3.2 Gantt Chart

The research project consists of two semesters. The author begins the first semester by attending the briefing through an online meeting on the Final Year Project and deciding on a title. She gathered the information for the research and decide on the proper method to be used as well as the tools and software after the title was approved. The author completed data analysis and began drawing during the second half of the first semester. Figure 3.2.1 shows the research flow for the first semester in the Gantt chart.

No.	Activities/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project topic selection.	No.	Sec.4													
2	PSM Briefing		N.X.													
3	Preliminary research work								break		1					
4	Proposal Defence					-			ter							
5	Detailed Design								nes							
6	Material Procurement	m	لم	4	R	1	2	3	id-ser	0	يبو	91				
7	Proposal draft report submission	ITI	TE	CNI	KAI	. M	AL/	AYS	Z IA I	IEL	AK	A				
8	Proposal report submission															
9	Presentation															

Table 3.1 Gantt Chart for Semester 1

3.3 Design Develop by Using Catia



Figure 3.2 Spur Gear

By using CATIA software, spur gear was developed based on the gear available in the online market. Important data and parameters are collected from the data provided. The objective of this project is to work on an automated modeling system for various types of equipment with a new way of solving modeling design problems through knowledge-based engineering in conventional design procedures. Knowledge-based engineering was developed into a practical way of visualizing production costs and allowing for product analyses by simulating gear development activities for production tools. Any errors in the design stage can lead to very high losses. It may be worth focusing on the design phase of the gear development to reduce development costs.

Formulas: BSS0.5-20				?	\times					
				Impo	rt					
Filter On BSS0.5-20										
Filter Name :]									
Filter Type : All										
Double click on a parameter to edit it										
Parameter	Value	Formula		Active	^					
N	20									
m	0.5mm									
Rp	5mm	= m*N/2		yes						
Rb	4.7mm	= 0.94*Rp		yes						
Ra	5.5mm	= Rp+m		yes						
Rd	4.375mm	= Rp-1.25*m		yes						
Relations\Formula.1\Activity	true				× .					
Edit name or value of the current parameter										
PartBody\Pad.3\FirstLimit\Length	3n	nm	-							
New Parameter of type Length Vith Single Value Add Formula										
Delete Parameter				Delete Form	ula					
OK Apply Cancel										

Figure 3.3 Parameters in CATIA



Table 3.2 Parameters of Gear

3.3.1 Orthographic View

The term "orthographic projection" refers to detailed line drawings that convey technical and dimensional information. The product is typically depicted in three views: front, end, and plan. The benefits of using orthographic are that it can reveal hidden details and all connecting parts.
The details were taken from gear that existed in the industry. It can be purchased from a specific online shop.



Figure 3.5 CATIA Drawing

3.3.2 Material Selection

The material selection of a model in CATIA defines how it responds to structural or thermal stresses imposed in each analytical stage. The last stage of the engineering design process is material selection. The development of engineering materials is the consequence of the desire to improve a material's structural and non-structural qualities. The role of design engineers is to undertake various tests and material analyses. These tests are both physical and virtual, thanks to the use of 3D solid modelling and simulation in CAD. Their mission is to find the greatest material alternative.

A virtual test of a 3D prototype of the real design will determine how appropriate the materials are for the design. For low load environments, usually, spur gear from brass is used as an instrument drive system. In this project, the same gear dimension is produced in SLS 3D Printing by using PA12 Nylon for this prototype. In CATIA, the material of the gear can be set up as shown in Figure 3.3.2.1



Figure 3.6 Choosing Material in CATIA

3.4 Analysis of the Product

Analysis of products from available gear in the market is important to reverse engineering purposes. All parameters and dimensions are taken from the existing gear by examining the gear to build a replica using 3D printing SLS based on the original design and their drawing. Only a few characteristics are required to identify the standard character. These factors may be measured or determined by SIMSOLID on geometric relationships. The following process is focused to reverse engineering these spur gears. It enables a more thorough examination of the design suitability of material choices and loading circumstances.

3.4.1 Structure and Specification Analysis

Structure and specification analysis is related to static and dynamic analysis of the spur gear tooth that contributes to establishing the maximum displacement, maximum produced stress, and the influence of stress fluctuation over time. By lowering the maximum induced stresses, the loading capacity and operating speed of a geared system may be raised.

3.4.1.1 SIMSOLID Static Analysis

SIMSOLID can do thorough analyses on certain materials such as stress distribution, displacement analysis, and strain analysis. Spur gear was the most fundamental gear, and it is used to transfer power between two parallel shafts with about 99 percent efficiency. It necessitates improved analytic techniques for developing heavily loaded spur gears for both powerful and silent power transmission systems. People are employing numerical approaches for Static and Dynamic Analysis of Spur Gear due to the advancement of computers. The finite element approach can supply motion on contact also the bending loads in gears, as well as transmission mistakes. In the past, gear analysis was performed using analytical approaches that required complex computations. Both static and dynamic loading conditions of gear can be examined by SIMSOLID, which is not the case with the Analytical technique.

3.4.1.2 SIMSOLID Displacement Analysis

An optimization modeling technique aimed at improving their displacement capacity. In this manner, the design parameters of the spur gears are systematically determined to achieve their optimal output displacements. A parametrically designed CAD model of the ideally manufactured gear is also created. To begin, the research creates tooth profile equations for gears on a rack cutter profile using the coordinate transformation and meshing equation. The encircling region is then represented by an involute curve, and an analytic formula is obtained.

3.5 Development and Fabrication of the Design

The combination of computing-aided design (CAD) and the production process will produce digital modelling and fabrication. Fabrication is one of the important steps to develop the product after it was designed. Fabrication relates to a lot of manufacturing processes such as forming, rolling, cutting, welding, bending, punching, drilling, machining, and a lot of other activities. Initial design prototypes, products, and even manufacturing equipment to enable customized fabrication of a product are all designed by design development and also a fabrication. Machining is one of the types in fabrication. There are three machines commonly used for fabrication which is CNC router, laser cutter, and 3D printer.

3.5.1 3D Printing (SLS Printing)

This project involves 3D Printing using an SLS machine that also known as Selective Laser Sintering. SLS used a high-power laser to sinter the small particle of powder and produced it into a solid structure. A high-powered laser is used in SLS 3D printing to bond powdered plastic material together into the required 3D forms. Parts that are highly detailed, sturdy, lasting, heat resistant, and flexible may be created with this process. The CO2 laser is used as a laser beam to the sinter PA12 NYLON thin powder that is layered on top of each layer.

3.5.1.1 Printing

In SLS printing the small particle of powder is sintered by using a high-power laser to produce a solid structure. By using the high power of a laser, SLS sinter the small particle of PA12 NYLON into the solid structure. By using the operation principle of SLS, powder of PA12 NYLON is sintered with infrared at an elevated temperature which makes the grain powder consolidate before being bound with the laser beam. The roller will spread a thin layer of powder followed by sintering according to the layers sliced from the CATIA. Next, the building platform is moving downward and leaving the gap at the top of the build cylinder. on the bottom of the feeders move upward to make the powder be gathered and pushed by the roller, closing the gap and formed the first powder layer. after that, the layer of the PA12 NYLON is heated to a temperature lower than the material's sintertion that known as the part of bed temperature. Then the laser beam scanning takes place in this layer, providing the energy to selectively sinter the particles following the geometry of the spur gear. After this powder layer has sintered, another is deposited and repeated until the desired object is finished.



Figure 3.7 Schematic draw of the 3D Systems Sinterstation (Pereira et al., 2012)

3.5.1.2 Cooling

The laser scans through the powder bed during the SLS process, and the main particle fusion takes place over a short period without mechanical pressure. The part is then cooled slowly, usually for a few hours. The exact cooling rate of every part is affected by a difficult series of events. In-process cooling is often uniform, based on several factors that make predicting and measuring difficult. Once the laser passes a layer, the area scanned is partially cooled by the new powder layer. Despite some cooling, in these selected areas, the starter temperature of the powder bed is probably high, depends on the laser parameters and the composition of the structure.

It may then be recharged further as it moves away gradually from the heaters, depending on the heaters' location that controls the temperature of the powder bed. That's why the design of the machine makes a major difference. Piston heaters, for example, reduce cooling in processes compared with only overhead heaters. The number and size of other components on the powder bed also affect the cooling of the process, since the scanning of subsequent component layers is delayed while other components are being scanned.

Cooling rates are generally slow because of the dependence on the conduction of the powder bed and because of its low therapeutic conductivity. Many laser sintering models fail to consider the cooling in the process and assume that the powder bed is cooled in its entirety at the end of construction.

3.5.1.3 Post-processing

This gear is manufactured using SLS 3D printing, which is highly accurate and strong. Due to the powder nature of the PA12 NYLON-based fusion, SLS printed components are finished with a polished, grainy finish. Post-processing of SLS components is common practice with a range of available techniques and finishes. SLS parts also receive regular coatings to improve performance. Additionally, a functional coating can occasionally compensate for the lack of feasible SLS material grades.

Remove the finished parts from the build chamber after a print job is completed, separate them, and clean them of any excess powder. Typically, this procedure is carried out manually at a cleaning station with compressed air or a media blaster.

To begin, cleaning up the unused powder from the gear that served as support during printing is the first step in post-processing an SLS-printed item. It was accomplished with compressed air and rice or copper fibre brushes. The parts are shipped with a powdery, grainy finish, and depending on their intended use, some surface work may be required to achieve optimal results. Sandpaper, a precision knife, and a few pliers are sufficient for sanding.

After part recovery, any remaining powder is filtered to remove larger particles and recycled. Due to the slight degradation of unfused powder when exposed to high temperatures, it should be replaced with new material for subsequent print jobs. SLS is one of the least wasteful manufacturing methods due to its ability to reuse the material for subsequent jobs.

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3.6 Product Testing RSITI TEKNIKAL MALAYSIA MELAKA

Every process of measuring the properties being called as product testing to determine if the requirement of the specification. Gear that has been produced by SLS 3D printing is tested to know and measure their properties. Two gear will be tested which is one from the PA12 NYLON and the original from brass material.

3.6.1 Tribology Properties Test

Tribology properties test is the way to know wear and friction happened between the surface in the motion condition. Friction and wear gives negatives effects on the material properties such as energy losses, vibration, heat, and noise generation, and can lead to component failure. By selecting the optimum material for the component it can improve the performance and durability, also can longer the lifetime of the machine components. The test sample is loaded with a flat or sphere-shaped indenter with a precisely specified strength. The inscription (a ball or pin) is fixed on a sturdy, rubber-free force-transducing lever. The resultant frictional forces between the pin are measured as the disc is spun (Tedesco et al., 2010).



Figure 3.8 Schematic diagram of the POD test set-up and Position of the electrostatic sensor (L. Chang et al., 2008)

3.6.2 Surface Morphology TI TEKNIKAL MALAYSIA MELAKA

Surface morphology is an advanced kind of spatial imagery that employs powerful microscopes to create pictures of products, samples, and objects not visible with a naked eye. These pictures are taken from a sample or product's exposed surface. 3D morphology for the machined PA12 Nylon gear and metal gear surface. With specified grinding speed (vs), axial feed rate, and radial feeding the processing parameters employed for the surface are. The abrasives of the work piece may be observed with micro-cutting traces and flaws in the grinding process. In reality, the micro-cutting action of vast quantities of abrasive particles concurrently is the compounded micro-cutting effect. Scraping, ploughing, and chip creation are the progressive operations of moulding. The ploughing effect was caused by the plastic uplifting of the surface

materials on both sides. These typically machined surfaces of the gears show a rough arrangement of the basic roughness.



CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In chapter 4, it focuses on overall analysis and result from the data obtained from the simulation that have been carried out. Throughout this data collection process, the sample of gear are printed out and the optimization has been done. The optimization of gear is carried out with a certain parameter that have been set up to determine the capabilities of the gear with different geometry in SIMSOLID software. All the gear samples will be compared to identify the best optimised gear based on the overall result. The simulation result represented in the term of Table, Graph and Figure.

4.2 COF Analysis for Pin-on-disc Analysis

To determine the coefficient of friction of the selected product, the pin-on-disc test was conducted using ASTM G99-05. In this test technique, a pin-on-disk equipment is used to determine the wear of materials while sliding, and the results are recorded in a laboratory setting. Materials are evaluated in pairs under settings that are intended to be non-abrasive. The main experimental regions to pay attention to while using this sort of equipment to evaluate wear are discussed in further detail. It is also possible to calculate the coefficient of friction.

4.2.1 Effect of Different Geometry On The COF

On the COF and wear rates of 3D-printed ABS pins with varying interior geometries, there is a synergistic impact of normal loads and sliding speeds when applied together. Regardless of the sliding speed, it was observed that the coefficient of friction (COF) decreased with an increase in the normal load for the various internal geometries. Although a high COF value was seen for the solid and rectangular internal geometrical structures at lower normal loads, this value was also observed for the square, circular, and triangular internal geometrical structures at lower and higher speeds, respectively (Abdollah et al., 2020).

4.2.2 COF Constant for SIMSOLID Analysis

Coefficient of friction for every geometry structure is constant according to pin on disc experiments. As SIMSOLID simulation, every geometry has been compared to get know which geometry has the best durability from displacement magnitude, von mises stress, equivalent strain and shear stress.



Table 4.1 Coefficient of Friction (Nordin et al., n.d.)

According to Figure 4.1 and Table 4.1, the SLS triangle structure has the lowest coefficient of friction (0.3852) when compared to the SLS square structure (0.3856) while sliding at 400rpm and 39.24N. COF SLS is reduced with the use of internal structure of the following shapes: square, solid, circle, rectangle, and triangle.



Figure 4.1 Coefficient of Friction

4.3 Non-Linear Analysis (SIMSOLID)

A non-linear simulation is one in which a structure's stiffness matrix varies over time. Non-linear stress-strain relationships are a common source of changes in material properties throughout the duration of a simulation, and non-linear stress-strain relationships are the most common cause of changes in material properties during the course of a simulation. Taking this into consideration, it would be beneficial to examine transient simulations in which material characteristics vary over time owing to factors such as temperature dependency. Large deformations, such changes in material properties, may also have an impact on the stiffness matrix, since the structure and reference frames of the model are moved. In the case of physical contacts, when load and stress are transmitted between two components that come into contact, resulting in a change in the stiffness of both, the same holds true. It is this lack of direct proportionality between stress and strain in a material that causes it to be classified as nonlinear in nature.



Figure 4.2 Force Applied For Simulation

Every structure with different geomety has been applied with same tangential force and radial force on the contact teeth of the gear for the simulation.

4.3.1 Displacement Magnitude

Structural loads are forces applied to the face of a component or assembly that cause the model to shift, deflect, and produce stresses and strains in the model. Displacement are specified in a single dialogue, and prescribed displacement are defined in a separate dialogue. In modelling, force is defined as a load placed on a model. The supplied value is understood as a total force applied to all of the chosen part faces, regardless of how it is expressed. Only the global X, Y, and Z directions are available for specifying loads and prescribed displacement. Each sample of the structure has been applied force displacement by different magnitude.

Each colour in these simulation results corresponds to a distinct amount of displacement. The red colour indicated the displacement magnitude's greatest value, while the blue colour indicated the displacement magnitude's minimum value. The magnitude of the

displacement value decreased from red to blue. The regions of those colours in Figures 4.3, 4.4, 4.5, 4.6, and 4.7 vary. This implies that each geometric structure produces a unique geometric output.



Figure 4.4 Displacement Magnitude Circle Geometry



Figure 4.6 Displacement Magnitude Square Geometry



Figure 4.7 Displacement Magnitude Triangle Geometry

Table 4.2 Min. and Max. Displacement Magnitude		
Geometry	Min. Displacement (mm)	Max. Displacement (mm)
Solid	8.2130e-10	2.5029e-04
Circle	1.7925e-08	2.7746e-04
Rectangle	ERSIT1.5622e-09 KAL M/	LAYSI2.6388e-04
Square	7.4551e-10	2.6303e-04
Triangle	2.1348e-05	2.5616e-04

According to Table 4.2, Figure 4.8 illustrates the bar chart of the maximum displacement magnitude for each structural shape. As can be observed, the maximum displacement magnitude of a circular structure is the largest (2.7746e-04), while the maximum displacement magnitude of a solid structure is the lowest (2.5029e-04). However, it may also be compared to the many simulated colours. A circular structure received the least amount of red area, but a solid construction received a significant quantity of red area. These colours were chosen to represent the important area of the item based on their value. This demonstrates that circular

geometry has a large displacement magnitude in comparison to circles, rectangles, squares, and solids.



4.3.2 Von Mises Stress

Von Mises stress is a number that is used to assess whether a certain material would yield or fracture under certain conditions. This kind of material is most often utilised for ductile materials, such as metals. The von Mises yield criterion states that a material will yield if the von Mises stress of a material under load is equal to or greater than the yield limit of the same material under simple tension. The von Mises stress of a material under load must be equal to or greater than the yield limit of the same material under simple tension.

Every colour of these simulation results was defined by a different value of the von Mises stress. The red colour showed the maximum value of the von Mises stress, while the blue colour described the lowest value of the von Mises stress. The value of the von Mises stress was decreasing from the red colour to the blue. Figure 4.9, 4.10, 4.11, 4.12 and Figure 4.13 have different areas of those colours. It means every geometric structure has a different geometric result.



Figure 4.10 Von Mises Stress Circle Geometry





Figure 4.12 Von Mises Stress Square Geometry



From Figure 4.14, the bar chart of the maximum von mises stress for every structure geometry has been illustrated based on Table 4.3. It can be seen that a solid structure has the highest maximum von mises stress (6.5799e-01), while a triangle structure has the lowest maximum von mises stress (3.7765e-01) compared to other geometries. However, it can also be compared to the different colours of simulation. A solid structure got the least amount of red area, while a triangle structure showed a lot of red area. These colours were described based on the value

to describe the critical section of the object. This shows that solid geometry has high von mises stress resistance compared to circles, rectangles, squares, and triangles, which have the least von mises stress resistance.



4.3.3 Equivalent Strain

Equivalent strain, expressed as a scalar, is a simple variable for reporting strain results across a body, albeit it does not include all of the necessary information about the strain condition in question. The Poisson's ratio is denoted by v. With respect to elastic strain, the equivalent elastic strain is defined as the upper limit for the values of strain at which the item will rebound and return to its original form once the load is removed. As described by the stress-strain curve, an elastic limit is a point on the stress-strain curve when an item transitions from elastic to plastic behaviour (Shrivastava et al., 1982).

A distinct value of the equivalent strain was used to define each of the various colours in these simulation results. The red colour represented the highest possible value of the equivalent strain, while the blue colour represented the lowest possible value of the comparable strain. The value of the comparable strain decreased as the colour of the equivalent strain changed from red to blue. There are various parts of those colours in each of the figures in Figure 4.15, 4.16, 4.17, 4.18, and Figure 4.19. The implication is that every geometric framework produces a distinct geometric output.





Figure 4.16 Equivalent Strain Circle Geometry

Figure 4.18 Equivalent Strain Square Geometry



The bar chart showing the maximum equivalent strain for each structural shape has been depicted in Figure 4.20, which is based on the information in Table 4.4. If we examine the maximum equivalent strain of different geometries, it can be shown that a solid structure has the greatest maximum equivalent strain (1.2420e-04), while a triangular structure has the lowest maximum equivalent strain (7.1282e-05). In comparison to the varied colours of simulation, it might be said to be analogous. A solid structure had the least amount of red area, but a triangular shape exhibited a significant quantity of red. Each of these colours was

characterised in terms of its monetary worth in order to describe the important portion of the thing. The fact that solid geometry has a high strain resistance is shown by the fact that it outperforms the least strain resistant shapes such as circles, rectangles, squares, and triangles.



4.3.4 Shear Stress

Shear stress is created as a result of shear forces. This term refers to a pair of forces **UNIVERSITITEKNIKAL MALAYSIA MELAKA** operating on opposing sides of a body that have the same magnitude but are acting in the opposite direction. Shear stress is represented as a vector quantity. This implies that, in addition to magnitude, the direction is also taken into consideration.

Each colour represents a distinct value of the shear stress in these simulation results. The red colour represented the greatest shear stress, while the blue colour represented the minimum shear stress. The shear stress value decreased from red to blue. Figures 4.8, 4.9, 4.10, 4.11, and 4.12 all include various sections of those colours. This implies that each geometric structure produces a unique geometric output.



Figure 4.22 Shear Stress Circle Geometry



Figure 4.24 Shear Stress Square Geometry



Table 4.5 has been used to create a bar chart showing the maximum shear stress for each construction shape in Figure 4.26. In comparison to other geometries, a solid structure has the greatest maximum shear stress (3.7529e-01) while a triangular structure has the lowest maximum shear stress (2.1488e-01). It may, however, be compared to the various simulated colours. The red area of a solid construction was the smallest, while the red area of a triangular structure was the largest. To indicate the crucial area of the item, these colours were specified

depending on the value. This demonstrates that solid geometry has a higher shear stress resistance than circles, rectangles, squares, and triangles, which have the lowest.



4.4 Prototype vs Actual Product

Prototypes are more than simply better presentations; they are also a very practical production method. Testing models such as prototypes are ideal since they are a tangible embodiment of the product and can be examined to identify any qualities that might make or break the design. Afterwards, manufacturers may use the knowledge obtained from the prototype to make adjustments to the final product. In this subtopics, show the actual product and the prototype.

There are significant distinctions between prototypes and finished items. There are three primary ways in which such disparities manifest themselves. For starters, prototypes are constructed from less costly components than final products. Prototypes of products that will be manufactured utilising titanium, for example, will often be created using plastic, white metal, and/or steel before going into production. It is thus more cost-effective to outsource the prototyping and employ a business that specialises in prototypes, even if the product will

ultimately be produced by a manufacturing company. In addition to saving a manufacturing firm time, labour, and money. Aside from that, prototypes are referred to as "dry run" items, and as a result, their manufacturing quantities are much smaller.



4.4.1 Product Comparison (picture of each angle SLS vs real)

There are significant distinctions between prototypes and finished items. There are three primary ways in which such disparities manifest themselves. For starters, prototypes are constructed from less costly components than final products. Prototypes of products that will be manufactured utilising titanium, for example, will often be created using plastic, white metal, and/or steel before going into production. It is thus more cost-effective to outsource the prototyping and employ a business that specialises in prototypes, even if the product will ultimately be produced by a manufacturing company. In addition to saving a manufacturing firm time, labour, and money. Aside from that, prototypes are referred to as dry run items, and as a result, their manufacturing quantities are much smaller.

4.4.1.1 Actual Product

Figure 4.28 shows every angle of the actual gear product from manufacturer.



Figure 4.28 Actual Product

4.4.1.2 SLS Prototype (Solid Geometry)

Figure 4.29 shows every angle of the SLS prototype gear for solid geometry.



Figure 4.29 SLS Prototype (Solid Geometry)

4.4.1.3 SLS Prototype (Circle Geometry)

Figure 4.30 shows every angle of the SLS prototype gear for circle geometry.



Figure 4.30 SLS Prototype (Circle Geometry)

4.4.1.4 SLS Prototype (Rectangle Geometry)

Figure 4.31 shows every angle of the SLS prototype gear for rectangle geometry.



Figure 4.31 SLS Prototype (Rectangle Geometry)

4.4.1.5 SLS Prototype (Square Geometry)

Figure 4.32 shows every angle of the SLS prototype gear for square geometry.



Figure 4.32 SLS Prototype (Square Geometry)

4.4.1.6 SLS Prototype (Triangle Geometry)

Figure 4.33 shows every angle of the SLS prototype gear for solid geometry.



Figure 4.33 SLS Prototype (Triangle Geometry)

4.4.2 Product Specification

Known as a product specification or product spec, a Product Specification is a critical product document that describes the primary criteria for developing a new feature, capability, or whole product. For product specification actual products and prototype has same size, same number of teeth but different material which affected to the weight.
	Actual Product	Prototype
Gear type	Spur Gears	Spur Gears
lo. of teeth	20	20
Bore (mm)	4.0	4.0
Iub Diameter (mm)	8.5	8.5
itch Diameter (mm)	10.00	10.00
Outer Diameter (mm)	11.00	11.00
ace Width (mm)	3.0	3.0
ub Width (mm)	7.0	7.0
eight (kg)	0.00430	0.00120
aterial	Brass	Nylon PA12
Y SURAINO		
مليسيا ملاك	نيڪني <i>ڪ</i> ل	اونيۇمرسىتى
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Table 4.6 Specification of Actual Products and Prototype

4.5 **Product Readiness**

Based on the simulation result, circle has the best displacement result compare to other internal geometry. But for von mises stress, equivalent strain, and maximum shear stress, solid geometry showed the best simulation result.

Geometry	Displacement	Von Mises	Equivalent	Max. Shear
		Stress	Strain	Stress
Solid	×	\checkmark	\checkmark	\checkmark
Circle	1	×	×	×
Rectangle	JAL MALAISIA ME	*	×	×
Square	×	×	×	×
Triangle	Eller *	×	×	×
	Ainn .			
.5.1 Potentia	l Application	کنیک	برسيتي تيد	اونيو

Table 4.7 Simulation Readiness

Nylon gears that have been machined are often employed in situations that need increased torque and power. A few examples of common uses for nylon gearing include conveyor systems, packing equipment, and industrial automation systems. Nylon is often used as a gear material in order to lessen the noise generated by a metal gear train or to reduce vibration generated by the gear train.

Using nylon gears as a failsafe in a complicated powertrain may also be a good solution. By incorporating a sacrificial nylon gear in the system as a failsafe, the designer understands that the system has the potential to fail catastrophically, and by doing so, they can avoid harm to the rest of the drive. It is the plastic gear that will break first when the system is subjected to a

peak load that exceeds that of the system's design specifications. This may save money on equipment expenditures or perhaps save the life of someone who is close.



CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter summarised the project's result and made suggestions for further investigation. In this study, the current gear industry has been selected for the purpose of analysing their parameters and comparing them with other internal geometric structures using the prototype generated in this research. To determine the endurance of each design, a few distinct geometric forms were developed and compared to one another. By simulating using SIMSOLID, we were able to finish the study project effectively. Among the topics covered in the section on conclusion are an overview of the research and an analysis of the findings. Conclusion The section on recommendations contains suggestions for future study and development of this project, as well as suggestions on how to improve it.

The goal of this research is to optimise the internal geometry of future gears in order to develop them. As previously mentioned, the primary purpose of this research is to build and analyse future gear with optimised shape in order to achieve the second objective. When the geometry is analysed, it is feasible to find the most optimum gear design, which is commonly employed in the manufacturing business.

The next step in this study is to use a 3D SLS machine to construct the gear that was developed before. The prototype for the gear was created using the existing gear as a starting point. CATIA has taken into consideration all of the specifications of the chosen gear. Internal geometry may be divided into four types of shapes: the circle, the rectangle, the square, and the triangle. SLS technology was used to produce all of the varied interior geometric structures on a 3D printer. Aside from that, the solid construction has also been printed in its whole.

Inside this end, using SIMSOLID simulation, we were able to evaluate the performance of the gear and analyse the developed product in terms of structure and performance in comparison to a traditional gear. The simulation results from SIMSOLID demonstrate that the values for each design are different. The circle structure has the greatest magnitude of displacement. The von Mises stress, shear stress, and equivalent strain of the solid structure, on the other hand, were the greatest. From mises stress, shear stress, and equivalent strain, the triangle shape structure exhibits the least amount of stress. Show, based on the simulation results obtained, that the solid construction of the gear has the optimum geometrical characteristics. Last but not least, the contemporary industry has produced the best structure for these gear designs that is solid geometry and does not have any internal geometry.

5.1 Recommendations

Recommended suggestions for further work include the following:

- Consider other type of the gear to be analyze such as helical gear, bevel gear, and worm gear.
- 2) Consider other geometry shape structure to be simulate such as random shape.

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