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Spur Gears Transmission Analysis on Countinous Passive Motion Machine Design for Shoulder Joint

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Abstract

An analysis of gear transmission on a continuous passive machine (CPM) from the 3-dimensional design has been carried out using SolidWorks software. Analysis of the strength of the gear structure is affected by the weight of the patient's arm. Analysis of gear transmission that is affected by the load of the passive arm uses static simulation, by entering the patient's arm load. The facilities used are static simulation with the condition of fixed geometry in the parts related of the shaft, the effect of gravity of $10\ m/s^2$, making mesh, and running simulation. The maximum stress that occurs in gear$_3$ $z = 100\ is\ 4.5524e + 006\ N/m^2$, the maximum stress on gear$_2$ $z = 80\ is\ 4.81729e + 006\ N/m^2$, the maximum stress on gear$_{100}$ $z = 20\ is\ 9.08982e + 006\ N/m^2$.

Keywords: mesh, static, simulation, continuous passive machine, spur gear.

1 Introduction

Continuous passive machine (cpm) is a therapeutic tool used to train patients in joint movements after joint surgery [1]. The CPM machine is designed to move flexion and horizontal adduction using spur gear transmission. The gears are used to reduce the speed from the actuator and increase torque, so that it can passively move the patient's shoulder to do therapy. With the development of computer aided design (CAD) technology is very helpful in designing a product or machine. The process of designing in manufacturing industries used a lot of time. An engineer who has experience in using CAD can use various tools/facilities in CAD software in various applications in mechanical engineering, so that the time spent designing can be done shorter, productivity and quality can be produced better. One CAD software for design and analyzing a 3-dimensional design is Solidworks.

The purpose of this study was to analyze the strength of material from the gear transmission to the patient's arm load. The strength of material of the gears are analyzed by the stress and strain on the gears. All analyzes of this study use SolidWorks software. Our main references are [2-5].

2 Research Methodology

To complete the analysis in this study, the steps taken before doing the simulation are as follows.

2.1. Research methods

The research methods is done by designing 3 Dimensional CPM machine, from the results of the design will be analyzed the transmission of straight gears. By using software, the stress and strain experienced by each gear that is exposed to the specified load will be carried out. The research method is carried out by the following steps:

a. Collect the geometry of the CPM machine that will be designed.
b. Design 3 Dimensional CPM machine with spur gear transmission using Solidworks software.

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c. Analyzing the strength of material of the spur gear transmission of the CPM machine designed with the influence of the load determined using Solidworks software.
d. Analyzing the strength of material of the spur gear of the CPM machine using Solidworks software.

2.2. Design Methods of 3-Dimensional CPM Machine

In the CPM machine that will be designed there are 2 gearboxes that are used to reduce speed and increase the torque of a DC motor actuator. Two gearboxes are used for flexion movement and horizontal adduction has the same transmission pair. The method for carrying out the analysis of CPM gears transmission using the SolidWorks software is as follows:

a. Design spur gear
    1. Determine the patient's arm load
    2. Determine the torque that is required for the movement of the CPM machine
    3. Determine the gear ratio used in design of the CPM machine
    4. Determine the level of spur gear transmission that used at CPM machine
    5. Determine dimensions, modules, number of teeth of spur gears based on the ratio of each gear transmission level
    6. Determine the material of spur gear in the design of CPM machine

b. Design of spur gear transmission.

It is assumed that the patient's arm weight is 5 kg and the patient's arm is 80 cm long, so that the torque produced by the arm is 20 Nm. Shown in the equation below.

$$T = ½\ arm\ length\ x\ arm\ weight\ x\ gravity$$
$$T = 40\ cm\ x\ 5\ kg\ x\ 10\ m/s2$$
$$T = 20\ Nm$$

The Dc motor actuator used has a torque characteristic of 1.5 Nm and a rotational speed of 70 rpm, so the gear transmission ratio is obtained by the equation

$$\tau_{nc} = \tau_d \times i \times \mu$$

Symbol and description:

$\boldsymbol{\tau_{nc}}$: torque needed

τ_d : DC motor torque

i : ratio

μ : efficiecy 75%

so obtained :

$$\tau_{nc} = \tau_d \times i \times \mu$$

$$i = \frac{\tau_{nc}}{\tau_d \times \mu}$$

$$i = \frac{20}{1{,}5 \times 0{,}75}$$

$$i = 17{,}75$$

From the results of the calculation the ratio is obtained at 17.75. The ratio value is increased for the safety factor to 20. The total ratio can be divided into 2 levels of gear transmission which are equal to 4 and 5. The gears are directly connected to the actuator $gear_1$, then transmitted to $gear_2$. $Gear_2$ and $gear_3$ are on the same axis. Next $gear_3$ is transmitted to $gear_4$. All gears are determined using the same module, which is equal to 1mm. Gear1 is determined to have 20 teeth. So that in the first transmission the number of teeth obtained in $gear_2$ is equal to:

$$i_1 = \frac{z_2}{z_1}$$

$$z_2 = i_1 \; x \; z_1$$

$$z_2 = 4 \, x \, 20$$

$$z_2 = 80$$

For second level spur gear transmissions obtained:

$$i_2 = \frac{z_2}{z_1}$$
$$z_2 = i_2 \; x \; z_1$$
$$z_2 = 5 \, x \, 20$$
$$z_2 = 100$$

From these calculations of the level of the spur gears transmissions ore obtained as shown in figure 1.

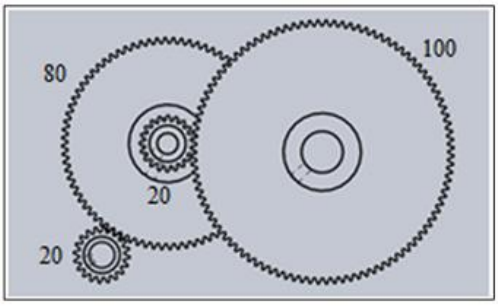

Figure 1. Spur gears transmission in CPM machine

c. Simulation Method of structural strength in Solidworks is as follows
   1. 1.Usefasilitas Simulation facility.
   2. Select the static test form.
   3. Insert the material used for spur gear.
   4. Determine the fixed of part design.
   5. Determine the gravity on the spur gear.
   6. Determine the part of spur gear that affected by patients arm weight/load and enter the value of the.
   7. Create a mesh on the spur gears.
   8. Run the simulation.

3 Results and Discussions

In this section will explain the results and discussion of the simulation of the spur gears that used in CPM machine. The analysis that will be carried out in this study includes:

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1. Analysis of spur gear 1 ($z = 20$)
2. Analysis of spur gear 2 ($z = 80$)
3. Analysis of spur gear 3 ($z = 100$)

3.1. Results

From he design of CPM machine is shown as show in the figure 2.

Figure 2. Design of CPM machine

1. Simulation analysis of load on gear1 $z = 20$

In the analysis of the results of the design of gear1 with $z = 20$ are shown as show Figure 3, Figure 4, and Figure 5.

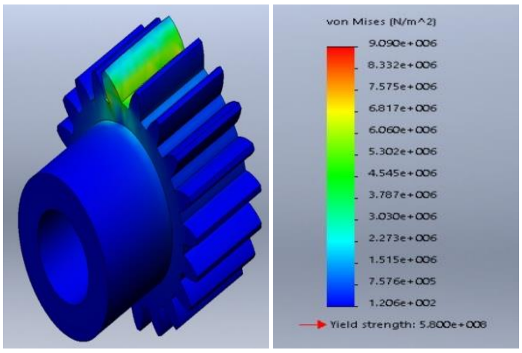

Figure 3. Stress on gear1 $z = 20$ due to the patient's arm load

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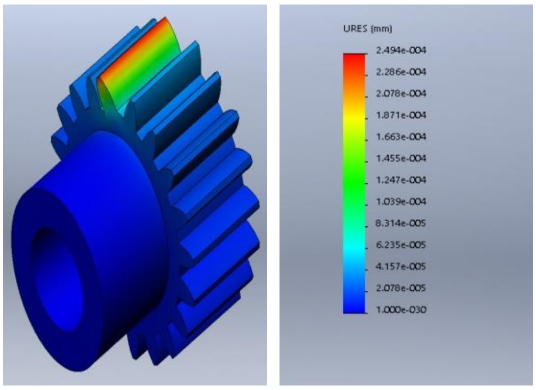

Figure 4. Displacement on gear1 $z = 20$ due to the patient's arm load

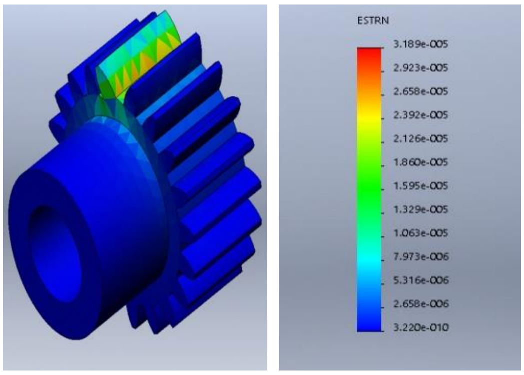

Figure 5. Strain on gear1 $z = 20$ due to the patient's arm load

Description spur gear1 $z = 20$:

Material	:	$1.0503\ (C45)$
Mass	:	$0.0277809\ kg$
Volume	:	$3.56165e - 006\ m^3$
Density	:	$7200\ kg/m^3$
Weight	:	$0.277809\ N$
Resultant Forces	:	$51.7429\ N$
Total Nodes	:	22126
Total elements	:	13140

Table 1. Table of results of analysis due to of patient arm load on spur gear1 $z = 20$

	Type	Min	Max
Stress	VON: von Mises Stress	$120.602\ N/m^2$ Node: 4339	$9.08982e + 006\ N/m^2$ Node: 5019
Displacement	URES: Resultant Displacement	$0\ m$ Node: 838	$0.000249418\ mm$ Node: 227
Strain	ESTRN: Equivalent Strain	$3{,}2199e - 010$ Element: 3550	$3.18916e - 005$ Element: 6033

In Table 1. It shows the results of the analysis of the structure due to the patient's arm load on the gear1 $z = 20$, the displacement/deflection on gear1 is $0.000249418\ mm$. And the strain that happened on gear1 is $3.18916e - 005$. The gear1 is still relatively safe because the maximum Yield Strength is $9.08982e + 006\ N/m^2$, and far below the allowable Yield Strength which is equal to $5.800e + 008\ N/m^2$.

2. *Simulation analysis of load on gear$_2$ $z = 80$*

In the analysis of the results of the design of gear$_2$ with $z = 80$ are shown in Figure 6, Figure 7, and Figure 8.

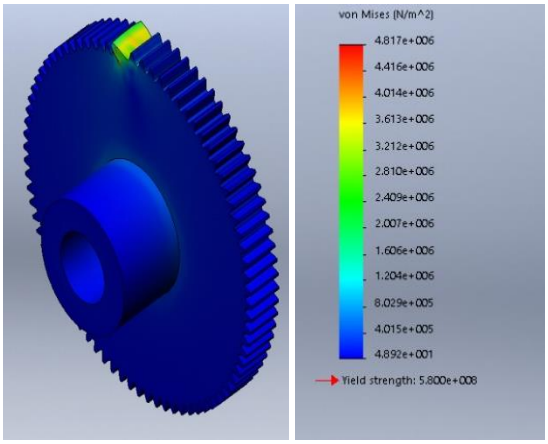

Figure 6. Stress on gear$_2$ $z = 80$ due to the patients arm load

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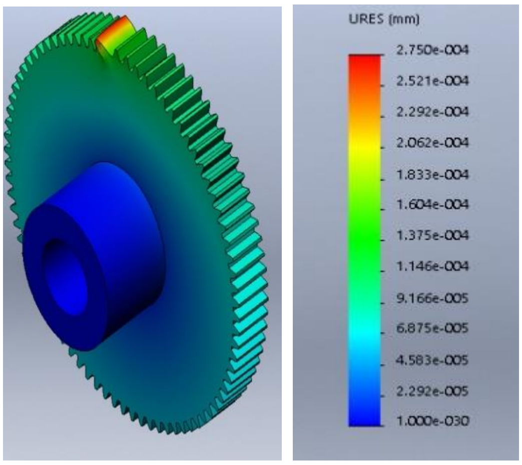

Figure 7. Displacement on gear$_2$ $z = 80$ due to the patient's arm load]

Description spur gear2 $z = 80$:

Material	:	$1.0503\ (C45)$
Mass	:	$0.45213\ kg$
Volume	:	$5.79653e - 005\ m^3$
Density	:	$7200\ kg/m^3$
Weight	:	$4.43087\ \ N$
Resultant Forces	:	$49.4847\ N$
Total Nodes	:	20410
Total elements	:	12580

Table 2. Table of results of analysis due to of patient arm load on spur gear$_2$ $z = 80$

Type		Min	Max
Stress	VON: von Mises Stress	$48.9205\ N/m^2$ Node: 15026	$4.81729 + 006\ N/m^2$ Node: 19255
Displacement	URES: Resultant Displacement	$0\ m$ Node: 110	$0.000274988\ mm$ Node: 1763
Strain	ESTRN: Equivalent Strain	$2.44294e - 010$ Element: 5820	$1.77017e - 005$ Element: 1609

Table 2 shows the results of the analysis of the structure due to the patient's arm load on gear$_2$ $z = 80$, the displacement/deflection on gear$_2$ is $0.000274988\ mm$ and the strain that happened on gear$_2$ is $1.77017e - 005$. The gear$_2$ is still relatively safe because the

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maximum Yield Strength is $4.81729 + 006\ N/m^2$ and far below the allowable Yield Strength which is equal to $5.800e + 008\ N/m^2$.

3. Simulation analysis of load on gear$_3$ $z = 100$

In the analysis of the results of the design of gear$_3$ with $z = 100$ are shown in Figure 9, Figure 10, and Figure 11.

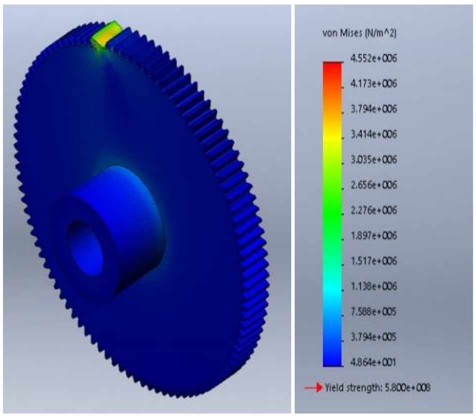

Figure 9. Stress on gear$_3$ $z = 100$ due to the patients arm load safe because the maximum Yield Strength is $9.08982e + 006\ N/m^2$, and far below the allowable Yield Strength which is equal to $5.800e + 008\ N/m^2$.

3.2. Discussions

Analysis of the strength of spur gear material due to patient's arm load, to analyze the gearbox transmission of the affected part of the transmission gear to transmit torque to the spur gear of each gears. This can be simulated because when the rotating gears of each gear will experience the same load and direction .

From the design and simulation the maximum stress on the gear$_1$ $z = 20$ is $9.08982e + 006\ N/m^2$. On gear$_2$ $z = 80$ the maximum stress that occurs is equal to $4.81729 + 006\ N/m^2$. The maximum stress that occurs in gear$_3$ $z = 100$ is equal to $9.08982e + 006\ N/m^2$. The value of maximum stress indicates that teeth of the spur gear is affected by load of patients arm. The results of the simulations show that material 1.0503 $(C45)$ still safe. This is indicated by the maximum stress occurs in each gear is still far below Yield Strength. Material yield strength is 1.0503 $(C45)$ which is equal to $5.8e + 008\ N/m^2$.

4 Conclusion

For designing and simulating three dimensions, it is very helpful in evaluating the design of a device. Loading on the simetris section can be assumed on one part that is exposed to the load of the tool. The analysis in this study was carried out with static loading. The possibility of analysis through simulation can still be done using the dynamic loading method

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