

# 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  $10 \text{ m/s}^2$ , making mesh, and running simulation. The maximum stress that occurs in gear<sub>3</sub>  $z = 100$  is  $4.5524e + 006 \text{ N/m}^2$ , the maximum stress on gear<sub>2</sub>  $z = 80$  is  $4.81729e + 006 \text{ N/m}^2$ , the maximum stress on gear<sub>100</sub>  $z = 20$  is  $9.08982e + 006 \text{ N/m}^2$ .

**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.

- 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  $5\text{ kg}$  and the patient's arm is  $80\text{ cm}$  long, so that the torque produced by the arm is  $20\text{ Nm}$ . Shown in the equation below.

$$T = \frac{1}{2} \text{ arm length} \times \text{arm weight} \times \text{gravity}$$

$$T = 40\text{ cm} \times 5\text{ kg} \times 10\text{ m/s}^2$$

$$T = 20\text{ Nm}$$

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

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

Symbol and description:

$\tau_{nc}$  : torque needed

$\tau_d$  : DC motor torque

$i$  : ratio

$\mu$  : efficiency 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<sub>1</sub>, then transmitted to gear<sub>2</sub>. Gear<sub>2</sub> and gear<sub>3</sub> are on the same axis. Next gear<sub>3</sub> is transmitted to gear<sub>4</sub>. All gears are determined using the same module, which is equal to 1mm. Gear<sub>1</sub> is determined to have 20 teeth. So that in the first transmission the number of teeth obtained in gear<sub>2</sub> is equal to:

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

$$z_2 = i_1 \times z_1$$

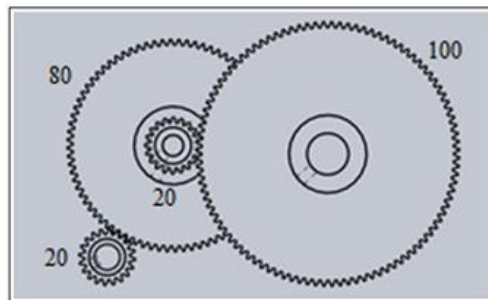
$$z_2 = 4 \times 20$$

$$z_2 = 80$$

For second level spur gear transmissions obtained:

$$i_2 = \frac{z_2}{z_1}$$
$$z_2 = i_2 \times z_1$$
$$z_2 = 5 \times 20$$
$$z_2 = 100$$

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. Use facilities 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:

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**

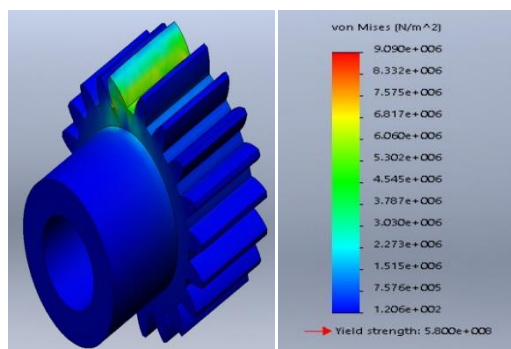
From the design of CPM machine is shown as shown in the figure 2.



**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 shown in Figure 3, Figure 4, and Figure 5.



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

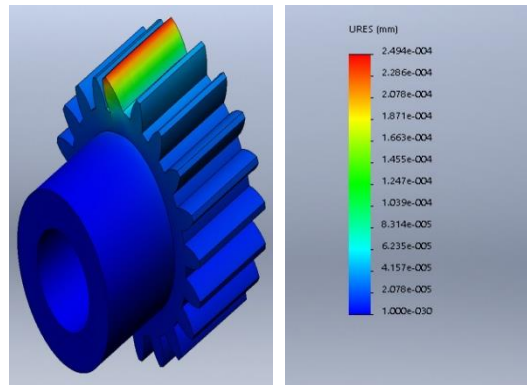


Figure 4. Displacement on gear1  $z = 20$  due to the patient's arm load

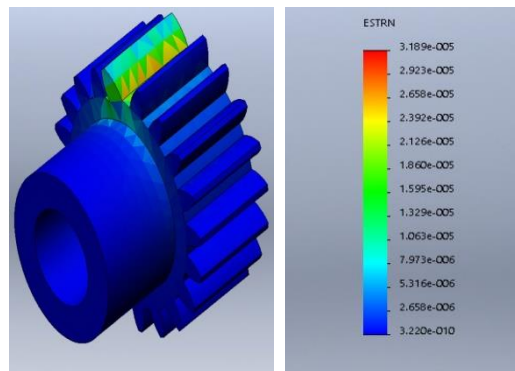


Figure 5. Strain on gear1  $z = 20$  due to the patient's arm load

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

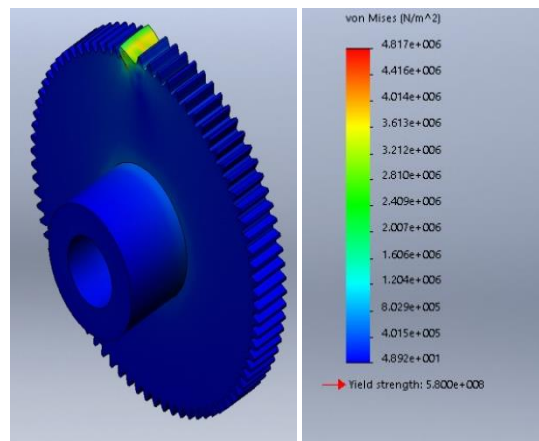
**Table 1.** Table of results of analysis due to of patient arm load on spur gear1  $z = 20$

	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  $N/m^2$ .

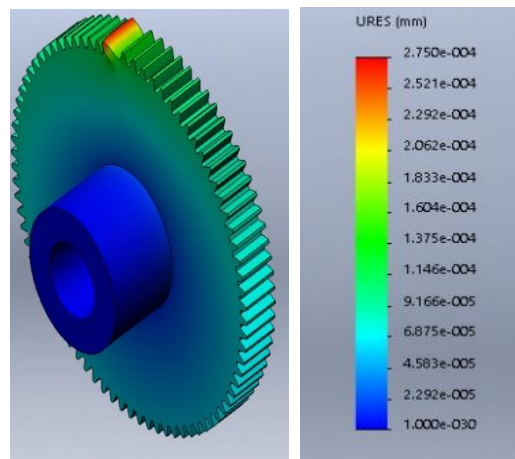
**2. Simulation analysis of load on gear2  $z = 80$**

In the analysis of the results of the design of gear2 with  $z = 80$  are shown in Figure 6, Figure 7, and Figure 8.



**Figure 6.** Stress on gear2  $z = 80$  due to the patients arm load





**Figure 7.** Displacement on gear<sub>2</sub>  $z = 80$  due to the patient's arm load]

Description spur gear<sub>2</sub>  $z = 80$ :

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<sub>2</sub>  $z = 80$

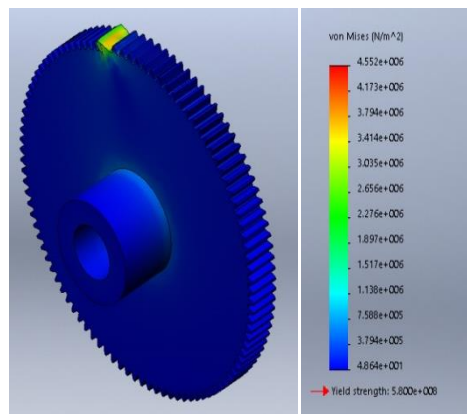
Type		Min	Max
Stress	VON: von Mises	$48.9205 N/m^2$	$4.81729 + 006 N/m^2$
	Stress	Node: 15026	Node: 19255
Displacement	URES: Resultant	0 m	0.000274988 mm
	Displacement	Node: 110	Node: 1763
Strain	ESTRN:	$2.44294e - 010$	$1.77017e - 005$
	Equivalent Strain	Element: 5820	Element: 1609

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

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<sub>3</sub> z = 100

In the analysis of the results of the design of gear<sub>3</sub> with z = 100 are shown in Figure 9, Figure 10, and Figure 11.



**Figure 9.** Stress on gear<sub>3</sub> 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<sub>1</sub> z = 20 is  $9.08982e + 006 N/m^2$ . On gear<sub>2</sub> z = 80 the maximum stress that occurs is equal to  $4.81729 + 006 N/m^2$ . The maximum stress that occurs in gear<sub>3</sub> 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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