ISSN: ٢٦٧٦-٥٧٦٤
www.jocrisar.ir
مجله پژوهش های معاصر در علوم و تحقیقات
سال پنجم، شماره ۵۲، آبان ۱۴۰۲

Study on design and material selection of a Spur Gear pair utilized in renewable energy devices

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Abstract

The main aim of this project is the modeling and the studying of the static stresses on spur gears of different materials for a mechanical solar tracker. It is worth mentioning that, Solar energy is a vast source of directly usable energy in order to generates other energy resources such as biomass, wind, hydropower, and wave power. Solar power is the major primary source of energy that can meet human needs in the future. Furthermore, Gears are mechanisms that transmit rotary motion from one shaft to another by matching up teeth together. In a mechanical power transmission unit and their durability led to their selection as a mechanical component in the tracking mechanism. this project dedicated investigation on design and analysis of two important characteristics of gears, e.g. the radius and the number of teeth.

Key words: solar energy, Gear, spur gear, energy harvesting, renewable energy

1. Introduction

Various solar tracking mechanisms have been designed and implemented by various designers around the world in order to reduce the cosine losses of incident radiation on solar panels. The face of the solar panel or reflective surfaces of a typical solar tracking system is adjusted to align with the sun as it moves across the sky. Every day, the system completes one rotation.

The tracker's construction is divided into three sections: mechanical, computer science, and electronics and electrical, in that order. The DC motors, worm gears, and the frame that housed the entire system make up the mechanical system. PV sensor, comparator circuit, and microcontroller make up the electrical and electronic system, which is then connected to the internet. Offered the cyclic dynamic and transient stresses built up in the tooth of the gear, the role of small spur gears in precise actuation for this purpose is critical. For this Job a pair of spur gear are usually used to drive a dual axis tracking system for simultaneous rotation around a vertical and horizontal axis.

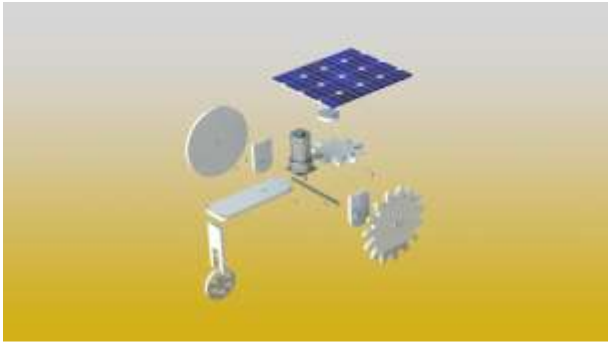

Fig. 1: solar panel and spur gear wheel.

To accomplish this, a gear mechanism is used that rotates at a rate that corresponds to the speed of the sun's movement. The time between sunrise and sunset is about 12 hours, and during that time the sun covers an approximate angle of 180 degrees. As a result, the gear mechanism's rotation speed must be adjusted so that it covers 180 degrees in 12 hours and returns manually. The solar module is attached to the solar panels so that it can rotate with the gear mechanism and track the sun's path. As a result, throughout the day, the sun's rays fall exactly perpendicular to the surface of the solar module, increasing the efficiency of power generation by the solar photovoltaic cell in the solar module. The gear mechanism's speed is adjusted with the help of a dead weight. The weight of the dead weight is calculated based on a 15 degrees gear rotation per hour. As a result, at the end of the day, we can achieve 180 degrees As a result, we will be able to archive at the appropriate speed.

Gears differ in length from the smallest in watches to the largest in lifting machines. Gears are made up of two types of teeth, one cycloidal and the other involute, and are one of the most important components in a mechanical power transmission system. The curved profiled (formed) tooth has an advantage over the cycloidal profiled tooth in that if the center distance of any wheel (gear) changes or shifts, the involute profiled (formed) tooth will maintain a constant velocity ratio, whereas the cycloidal profiled tooth will not.

Usually, the tooth mesh characteristics, such as the tooth contact zone contact ratio, are commonly affected by changing the pressure angle. The static stress analyses of spur gears using Finite Element Method (FEM), such as beam strength, bending strength, and contact stress, were discussed, where the step-by-step FEM was discussed and different gear calculations and material selection comparison was carried out in this project.

The FMEA's aim is to bring steps to eliminate or reduce failures, beginning with the most critical. Failure modes and effects analysis also documents current knowledge and actions about failure risks, which can be used to improve performance in the future. To avoid failures, FMEA is used during the design process.

A number of studies are conducted in this project a FEA software (ANSYS) to further the basic understanding of gears. With a better understanding of spur gear behavior, such as static stresses and deformations, designers will be better able to design high-performance transmission systems that meet requirements in a variety of operating conditions. Based on The results it is possible to establish the advantages of metallic or non-metallic gears. There are significant benefits to using FEA: Comprehensive result sets, generating the system's physical response at any location, including some that might have been overlooked in a traditional analytical approach. Simulate load conditions and failure modes that are potentially dangerous,

destructive, or impractical in a safe manner.

2. Solar Tracking Application

Solar trackers are devices that allow solar panels, reflectors, lenses, and other optical equipment to be oriented toward the sun. Trackers are used to orient the collecting system to optimum energy output because the sun's location in the sky varies with the seasons and time of day.

When deciding whether or not to employ trackers, there are several aspects to consider. The solar technology utilized, the quantity of direct solar irradiation, feed-in tariffs in the region where the system is implemented, and the cost of installing and maintaining the trackers are only a few of them.

Concentrated applications, such as concentrated photovoltaic panels (CPV) or concentrated solar power (CSP), need a high level of precision to guarantee that the sunlight is properly focused to the focal point of the reflector or lens. Tracking is not required for non-concentrating applications, although it can enhance the overall power generated by the system. Photovoltaic systems with trackers and high efficiency panels can be highly effective.

Solar trackers come in a variety of shapes, sizes, and prices, as well as levels of complexity and performance. Single axis and dual axis trackers are the two most common types of trackers.

single axis

A horizontal or vertical axis can be used in solar trackers. In tropical locations where the sun rises quite high at midday, yet the days are short, the horizontal type is employed. In high latitudes, when the sun does not rise very high, but summer days can be quite lengthy, the vertical type is utilized. Single axis trackers are utilized with parabolic and linear Fresnel mirror designs in concentrated solar power systems.

Dual axis

Solar trackers contain both a horizontal and vertical axis, allowing them to follow the sun's apparent motion from almost anywhere on the planet.

Solar power towers and dish (Stirling engine) systems are two CSP applications that use dual axis tracking. Due to angle errors caused by larger distances between the mirror and the central receiver in the tower construction, dual axis tracking is critical in solar tower applications.

Many classic solar PV systems use two-axis trackers to keep the solar panels aligned with the sun's beams. By maintaining the panels in direct sunlight for the maximum number of hours each day, the overall power production is maximized.

3. Spur Gears

What is spur gear?

One of the most common forms of precision cylindrical gears is spur gears. Straight, parallel teeth are positioned around the perimeter of a cylinder body with a central bore that fits over a shaft in these gears. The gear is machined with a hub in various variations, thickening the gear body around the bore without altering the gear face. The center bore of the spur gear can also be broached to allow it to fit onto a splined or keyed shaft.

Spur gears are mechanical devices that transmit motion and power from one shaft to another through a sequence of matched gears to raise or decrease the speed of a device or multiply

torque.

Spur gear application

In a mechanical arrangement, spur gears are used to transfer motion and power from one shaft to another. This transference can change the working speed of machines, double torque, and allow fine-tuning of positioning systems. Because of their architecture, they're ideal for slower processes or settings with a higher noise tolerance.

Some of the typical industrial applications include:

- Transmissions
- Conveyor systems
- Speed reducers
- Engines and mechanical transportation systems
- Gear pumps and motors
- Machining tools

4. Material Selection Strategy

Material selection is an extremely essential and significant phase in the design process (Spur Gear in this case). If a material is mistakenly selected, this can not only lead to failure, but also add up to the expense of production. The choice of the best material for the component includes the choice of material that meets the necessary criteria and retains all its qualities in the fabricated component. And therefore, a prominent method of selection is needed.

The Steps below shows the Strategy for this research:

۱. DESIGN REQUIREMENTS:

- FUNCTION: High Bending Strength of the Spur Gear
- OBJECTIVE: Minimizing Mass of the Spur Gear
- CONSTRAINTS: Spur Gear Should not fail via Bending

۲. FREE VARIALBLES:

F, Kv, Pt, m, Z, Kw, n, V

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٣. SCREENING:

Candidates who cannot execute their job are eliminated through screening because some or all of their qualities lay outside of the limitations that set by the constraints.

٤. RANKING:

The ranking provides excellent standards that enable ranking of materials by their ability to perform well.

٥. DOCUMENTATION:

To make a selection, research the history of the Top candidate. After rigorous analysis of the constraints, targets, functions and free variables, the material index is found (the material index is evaluated in the later part of this study). The function need, the geometry, and the characteristics of the material from which it is constructed [6] determines the performance of the structural element according to three things in the Ashby method. The equation describes the text above:

$$p = \left[\begin{pmatrix} Functional \\ requirements \\ f \end{pmatrix}, \begin{pmatrix} Geometric \\ parameters \\ G \end{pmatrix}, \begin{pmatrix} Material \\ Properties \\ M \end{pmatrix} \right] \quad \ldots (1)$$

4.1. OBJECTIVE OF THE SPUR GEAR

The main goal of the design is to reduce the spur gear mass. To accomplish so, we must first of all search for the equation which describes the Spur Gear mass. The spur gear mass may be determined by imagining Spur Gear as a cylinder with a face width of Spur Gear and a radius equal to half the spur gear diameter.

The Spur Gear mass thus comes from: -

$$M = \pi \left(\frac{PCD}{٢}\right) F\rho \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

And,

$$٨□ \le F \le ١٢□ \rightarrow F = C_١ m, (where: ٨ \le C_١ \le ١٢) \quad \ldots\ldots\ldots\ldots (3)$$

$$PCD = MZ \quad \ldots\ldots\ldots\ldots (4)$$

The equation of mass (2) will be:

$$M = \left(\frac{\pi Z^٢}{٤}\right) C_١ m^٣ \rho \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

5. CONSTRAINTS OF THE SPUR GEAR

The Spur Gear is developed in two ways:

a) Bending Strength.
b) Wear Strength.

The Spur Gear should be built with pitting resistance when the wearing limitation of the gear has the highest importance. But the Spur Gear is designed using the criterion of bending stress fatigue in this Research since it is the industry's major need. The fatigue strength (S) of the spur gear should according to the principle of bending strength be more or equal to the bending stress of the spur gear teeth.

$$\sigma \le S \quad \ldots\ldots\ldots\ldots (6)$$

In line with the Lewis theory Spur Gear has to be able to resist the tangential burden (Pt).

It's rather straightforward to compute the material index for the gear using the Lewis Bending stress equation. The Lewis hypothesis shows the Tangential force below:

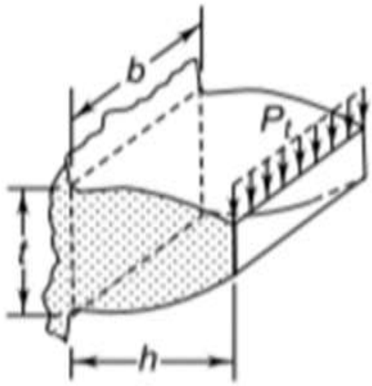


Fig. 2: Gear tooth as a Cantilever Beam

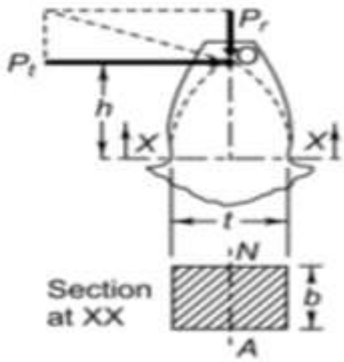


Fig. 3: Gear tooth as parabolic beam

In Fig. (2) Face width is designated as b, but we will continue to use F as Face width

Stress may be derived using the Lewis equation:

- $\sigma = \frac{K_v P_t}{F\ m\ y}$ ……… …… (7)
- $P_t = \frac{٦٠٠٠٠ (Kw)}{\pi\ P\ C\ D\ Z}$ ………… …… (8)
- $V = \frac{\pi\ PCD\ n}{٦٠٠٠٠}$ …… ………… (9)
- $K_v = \frac{٦.١+V}{٦.١}$ …………

…… (10)

Using equation (3), (4), (8), (9), (10), we get:

❖ $$\sigma = \frac{\left(\frac{٦.١+V}{٦.١}\right)\left(\frac{٦٠٠٠٠(Kw)}{\pi m Z^{٢}}\right)}{C_{١} m^{٢} Y}$$ …… …………. (11)

After substituting eq (9) in eq (11), we get

❖ $$\sigma = \frac{٦.١[٦٠٠٠٠(Kw)]+\pi\, m\, Zm\, (Kw)}{٦.١\, \pi\, Z^{٢}\, m^{٣}\, Y\, C_{١}}$$ ………… ……... (12)

Let us consider the following in order to simplify the computations in this study:

❖ $A = ٦.١\,[٦٠٠٠٠(Kw)]$

❖ $B = \pi\, Z^{٢}\, (Kw)$

❖ $C = ٦.١\, \pi\, Z^{٢}\, Y\, C_{١}$

Thus, the final equation is:

❖ $$\sigma = \frac{C+(B\, m^{٢})}{A\, m^{٣}}$$ ………………… …… (13)

As a function of strength (S), we look for module (m) we have to solve it by putting the equation (13) into the equation (6). Taking into account the maximal condition, we solve $(\sigma = S)$. Because the equation is difficult, it might be beneficial to use the mathematical tool that is offered by the computer. The three solutions are provided below (when x=m) Because below is the equation of order 3 in m:

Since two of the module's solutions are imaginary, we just need to evaluate the actual module solution. The module was determined to predominantly be proportional to the (S^{-1}) after replacing the actual solution (m) in eq (5). The performance of the structural element i.e., Spur Gear is therefore determined by:

❖ $$P(performance) = Mass(m) \propto \left(\frac{\pi Z^{٢}}{٤}\right) C_{١} \left(\frac{\rho}{S}\right)$$ …………. (14)

It is apparent from the preceding equation that the Spur Gear Material Index is $\left(\frac{S}{\rho}\right)$ the Maximization of the Material Index will lead us to a Minimized Mass, and therefore our objective is achieved. When the performance equation is examined, two essential material characteristics are shown to minimize the weight. One of these is the fatigue of the material of the gear, which is closely linked with the material's ultimate tensile strength (Sut). The strength therefore needs to be strong, but the density is low so that the weight of a spur is minimized. S must thus be high in order for the material to be selected based on the failure to bend fatigue.

6. APPLICATION OF ASHBY CHART

There are many materials, and there are many properties for everyone. We need to show and compare them in a nice manner. A helpful approach is to draw them into material property charts with a property on one axis and a different property on the other. Sometimes it is termed bubble or ASHBY diagrams. The values of each material vary according to the precise composition, grade, heat treatment, supplier etc. The materials on the chart are represented as "bubbles" or ellipses whose width and height determines the value of the characteristics. Note: the statistics of the material class acquired from the diagram are approximate, given that a certain material class may have numerous variants. The chart includes properties like as strength, youth modules, density, thermal expansion, thermal conductivity, energy embodied per m3, volume, etc. These diagrams can be utilized in various ways. They are interactive in GRANTA EduPack and allow you to learn more about a property or substance. The strength vs. density chart, shown below is to be looked at during this research.

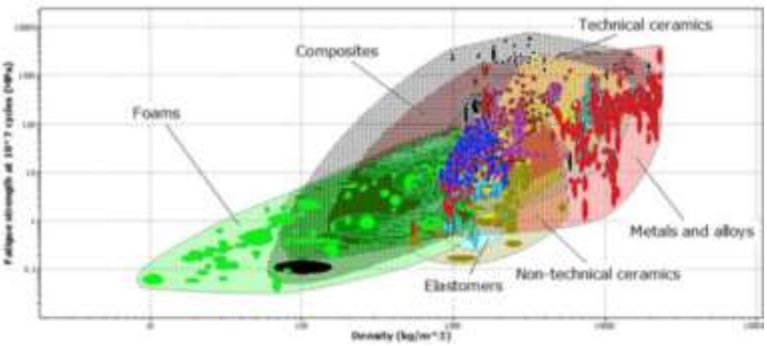


Fig. 4: Material Fatigue strength Vs. density

6.1. Screening

To carry out the screening procedure, the following steps should be carefully carried out.

a) We have got MI (Material Index) = $(\frac{S}{\rho})$, we have to improve our strength to raise (MI). Therefore, we must use the guideline of selection indicated by $(\frac{\rho}{S})$, instead of (σ), we used (S) as Strength to prevent misunderstanding We shall continue (Selection guideline is shown in the following graph).

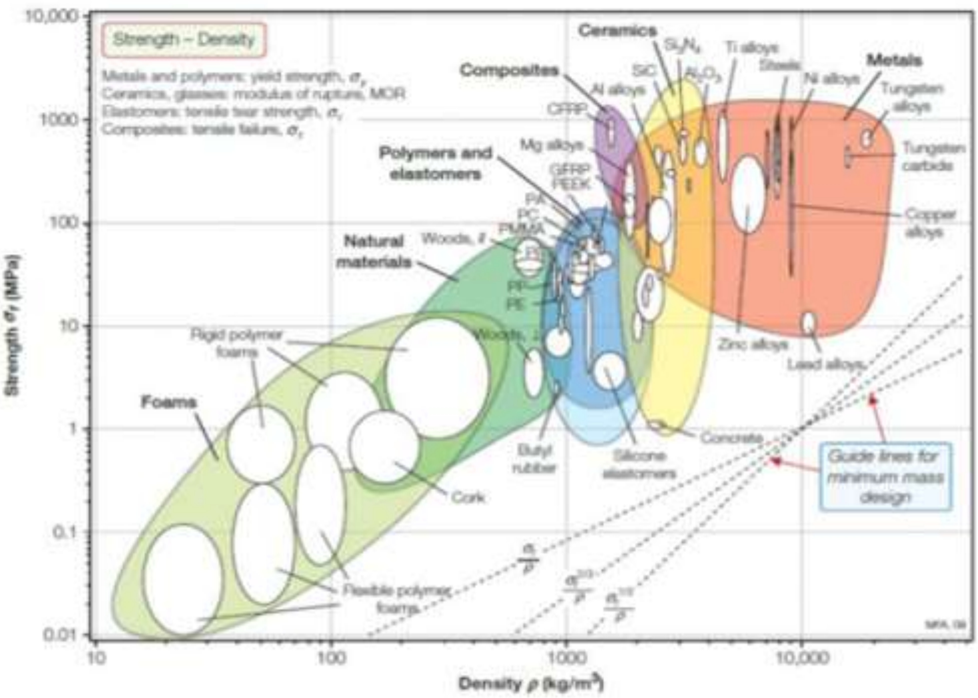


Fig. 5. Strength Vs. density graph showing selection guideline

b) Translate the chosen directive parallel to yourself so that we acquire the most materials above it (shown in figure 7). High strength, high density and vice versa are found in materials higher in the Guideline. The path divides the materials removed (grey locations). In the light of the material index, the aforementioned materials can be a contender. In this study, various materials were labeled as shown in Figure 7 for the design of spur gears.

c) Choose the most appropriate material for the specifications. In these cases, the materials' metal type is picked as equipment materials are often picked from metals for purposes in industrial engineering. (In figure 7 Strength Vs Density graph of only metals is shown).

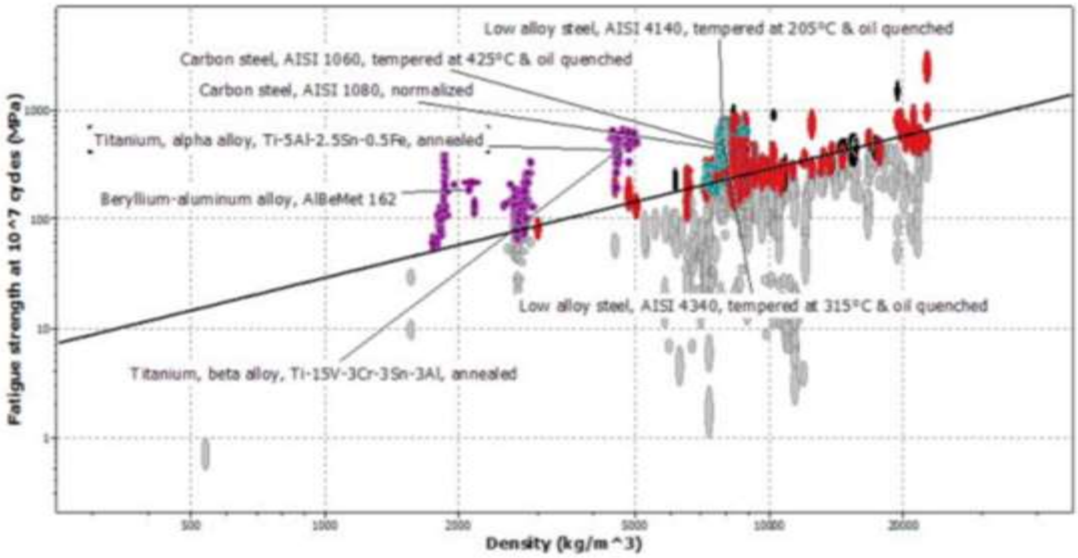


Fig. 6: Strength Vs. Density graph only for metals

Table 1: Material index

No.	Material	Material Index Value
1	Titanium, beta alloy, Ti-15V-3Cr-3Sn-3Al, annealed	0.105
2	Titanium, alpha alloy, Ti-5Al-2.5Sn-0.5Fe, annealed	0.0958
3	Beryllium-aluminium alloy, AlBeMet 162	0.0901
4	AISI 4140 tempered @205C & oil quenched	0.0811
5	AISI 4340 tempered @315C & oil quenched	0.0808
6	AISI 4140, tempered at 315°C & oil quenched	0.0738
7	AISI 4340, tempered at 425°C & oil quenched	0.0711
8	AISI 1080 tempered @205C & oil quenched	0.0656
9	AISI 1080 tempered @425C & oil quenched	0.0649
10	AISI 1060, tempered at 425°C & oil quenched	0.0572
11	AISI 4140, normalized	0.0551
12	AISI 1080, normalized	0.0547

Table 2: Material properties

No.	Density, kg/m3	Young Modulus, GPa	Yield Strength, MPa	Tensile Strength, MPa	Hardness, HV	Poisson's ratio
1	4750	108	749	770	225	0.35
2	4460	107	758	793	344	0.32
3	2070	179	193	262	115	0.165
4	7800	208	1480	1600	455	0.285
5	7800	205	1430	1550	435	0.285
6	7800	208	1290	1400	400	0.285
7	7800	205	1230	1320	385	0.285
8	7800	200	880	1180	360	0.285
9	7800	200	855	1160	350	0.285
10	7800	208	685	965	280	0.285
11	7800	208	595	915	275	0.285
12	7800	200	470	905	270	0.285

6.2. Ranking

A list of Potential Candidate materials may be found in the table above. The materials listed above meet the necessary Design Requirements and also adhere to the Bending Failure Constraint. We will also evaluate the relative cost per unit volume and the manufacturability when choosing the best material from the reduced down selection. The plot of the Relative cost per unit volume and Strength is depicted in the chart below. After converting the $MI = \left(\frac{S}{\rho}\right)$guideline, it is easy to conclude that the Ti alloys are at the top of the Line and hence are too expensive to be used in the gear manufacture.

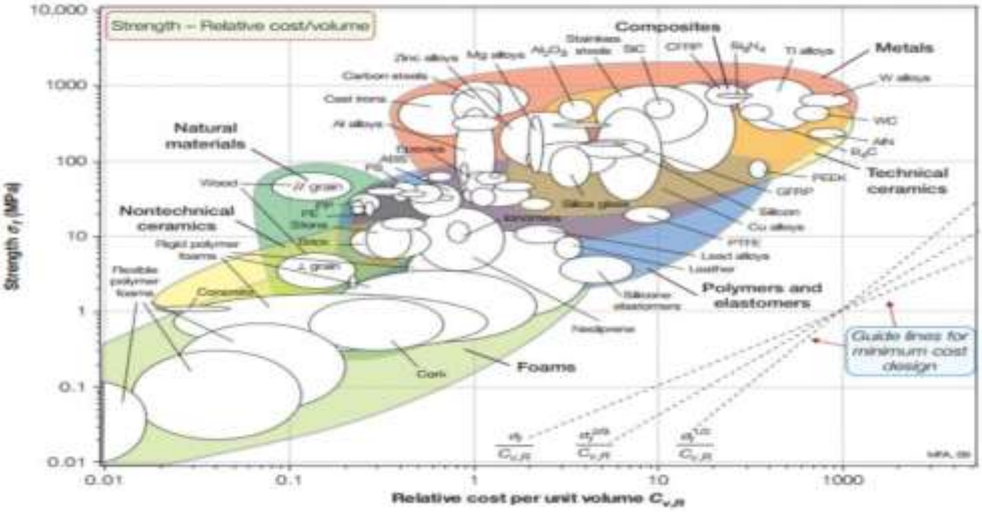


Fig. 7: Relative cost Graph

AISI 4140, tempered at 205°C and oil quenched, was found to be the lightest steel. The heaviest suggested material, on the other hand, was determined to be around 15% lighter than the lightest steel. In comparison to the lightest steel, the weight decreases for the two suggested materials, titanium alpha alloy and beryllium-aluminum alloy, was roughly 30% and 51%, respectively. When using the heaviest steel (AISI 1080, normalized), the weight gain might be as high as 63 percent [3]. Such an approach can lead to new material applications and make the work easier (especially for materials with low cost, such as Ti alloys and BeAlMet).

6.2. Documentation

Iron, steel, bronze, and phenolic resins are commonly used in gears. Gray cast iron gears are inexpensive, have great machinability, are quieter, and have a high wear strength. Because of their limited strength, they are not recommended for long-term usage. Although bronze is not often utilized in spur gear design, it is widely utilized in worm gear construction due to its ability to tolerate high sliding velocity. It is easy to work with, has a low coefficient of friction, and may be utilized in areas where corrosion is a big issue. Steels may be divided into two categories: alloy steels and plain carbon steel. Plain carbon alloys often contain Mg and Si, whereas alloy steels often contain Ni, Cr, Mo, and Mg and Si. Alloy steels are more durable and have a higher fatigue strength than ordinary carbon steels. Steels gears are costlier, but they can bear more weight. When the load is modest, and the pitch line velocity is low, non-metallic gears are usually utilized. Pinning are often composed of phenolic resins like Bakelite or Celeron, with cast iron as the counterpart. They're tolerant with tooth profile mistakes. They have a low Young's Modulus and are water-sensitive.

7. Design Analysis

7.1. Literature review

In this section, the aim is to investigate the spur gear's loading capacity, vibrations, contact stresses, bending stresses and life expectancies between metallic and non-metallic spur gears.

Polymer gears in solar tracking

In this part, it explains the design and study undergone on the spur gear and it is expected to stand in the metallic gears of a solar tracking applications utilizing gears made of polymer in order to decrease the weight and the disturbing noises. A spur gear sample model that was designed on a software called pro-E model which then was uploaded on the Ansys software so that a test of applying normal load condition took place. The important objective in this part is to investigate the various types of polymer gears such as nylon. The activity of polycarbonate analyzed with an equivalent gear made of metal like a casted iron. Resulting the investigation utilizing a Finite Element Analysis (FEA) method, which can help in understanding that if a composite gear is designed right and have been tested will allow us to gain an important factor such as cheap cost, disturbing sounds, vibrations and undergoes its process relatively to metallic gears. According to this study, gears made of nylon are advisable for such applications like solar tracking undergoing a specific load position in correlation with a cast iron spur gear [1].

Stress analysis of teeth in spur gears

In this part, the stress examination of teeth for a spur gear is to obtain the peak touching stress in the gear tooth. The outcome was found using finite element analysis in comparison with analytical hertz equation standards. Using Ansys design modeler, the assembly and modeling for a spur gear took place where the stress if a spur gear tooth was examined. We found out that both outcomes of FEA and hertz equation were closely related. Due to the deformation arrangement of grey cast iron and steel, it results in a low peak values regarding the grey cast iron and the steel gear deformation [2].

Material investigation

In this part, both metallic and non-metallic materials are going to be examined using cast iron as a metallic material and nylon as a non-metallic material. The headstock gear box of a lathe machine will undergo a stress examination analyzed through FEA. By the Lewis and AGMA formulas, the systematic bending stress can be computed. For further acceptance of the result obtained from the systematic computation and the FEA method, they will be brought in comparison to each other. Closing in the analysis, we found out that the FEA method (Ansys software) has an outcome of the stress distribution that is in satisfactory with the systematic outcomes. Likewise, the non-metallic material is capable to perform in the applications of a metallic materials due to the fact that non-metallic materials grants an extra advantages in the means of low cost, less noise, less vibration, self-lubrication and simple manufacturing [3].

Free vibration behavior of composites of spur gear

The aim in this part is to examine the composites spur gear free vibration behavior utilizing the FEA method which can be expressed as (FSDT) first order shear deformation plates theory. The FEA analyzed the composite gear in the means of four and eight nodded quadrilateral elements with five degrees of freedom for every single nods. By MATLAB the FEA computation of the composite gear is coded and modelled. Depending on the numerical analysis executed for the spur gear resulted in the development of the MATLAB codes verifying feasible outcomes. In conclusion the current FEA code outcome is in satisfactory with the ones referred to. Theoretical frequencies found for composite spur gear utilizing MATLAB are introduced. Furthermore we obtained that the natural frequencies increased ones the fiber orientation increases [4].

Relative performance of materials

In this part the relative performance spur gear of 30% for each glass filled PA66 and glass filled PEEK were analyzed at divers-able velocity and torque power. The FZG test machine was utilized for a wear test between the experimental spur gear tooth and spur gear pairs. There was a reduction in weight and it was obtained by 0.0001 g precise machine for weights, furthermore the temperature of the gear tooth’s was obtained by an impact infrared thermometer. In conclusion, the experimental outcomes of the PEEK GF30 and PA66 GF30 gears are not close neither in velocity nor in torque. Once the torque increases the tooth temperature increases draws towards the thermal softening of gear tooth that allows specific wear rate to increase. The relative outcomes of PEEK GF30 gear and PA66 GF30 gear results that the specific wear rate of PEEK GF30 is much lesser than the PA66 GF30 in velocity and torque. This results in allowing the PEEK GF30 to have higher torque transmission capacity than the PA66 GF30 [5].

Computer aided analysis of spur gear

In this part by utilizing a software called Anasys we can obtain the static load, bending stress and contact stress on the tooth of the spur gear. The Lewis formula and hertz equation are applicable for the systematic computation of bending and contact stress. We noticed that the systematic outcome found using hertz equations and Lewis formula relatable to the FEA results of spur gear, take into account that when comparing the FEA outcome are much of a problem solver software and its utilized for other examination function [6].

Stress computation at different states

The aim in this part is to examine the different stress states of spur gear. It’s computed that the radial and tangential forces that operates on different marks on the basis we can examine by implementing the forces. With Ansys software the contact and bending stress on the tooth of the spur gear are obtained gears which are machine elements utilized to transfer power between the rotational shafts by the engagement between teeth. The most common application of gears is to transmit power in the wooden mechanical world. There are a variety of different types of gears all the way from a tiny sized gear in watches to a large size of bridge lifting mechanism [7].

Wearing of spur gear

In this part, due to friction activity of the spur gear wears in the mid of gears that are meshed or even the occurrence of the undesirable elements such as dust fragments or metal ones, which decreases life time limit and its efficiency. It’s very important to take in account the life expectancy and strength of an object ones the wear have appeared on the teeth’s surface [8].

Advanced touched stresses in spur gear mating

A spur gear pairs were discharged from a lathe gearbox to perform a contact stress testing on the teeth. By assumption gears contact fail can be solved using hertz contact stress to analytically finding out proper values for such a given material. Utilizing hertz equation to solve the gear contact stress is basically brough for a touching in mid of two cylinders. Experimentally these touching stresses are computed by another module, yet these outcomes are related with the outcome found modelling analysis by Ansys [9].

Ansys software outcomes

This part explains the 3-dimensional model of the gear following pinion with mesh. The FEA method has been utilized to examine the static condition of gears then it computes systematically the peak stresses. There's a contact between the spur gears in the means of asymmetric and symmetric mating spur gear adjustments. The parameters of the spur gear are shown in table (3).

Table.3: Parameters

Parameters	Gear	Pinion
Number of teeth	14	17
Module (mm)	4	4
Gear ratio	1	1.21

The following figures shows the 3d model of the gear followed with the pinions. In order to gain a fine outcome, the right FE mesh is needed.

Fig.8: solid model assembly.

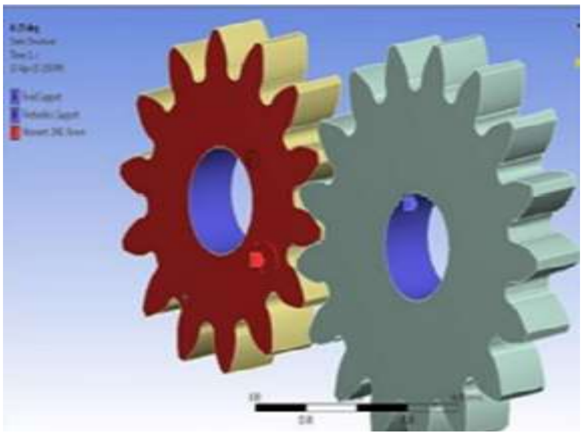


Fig. 9: the boundary condition.

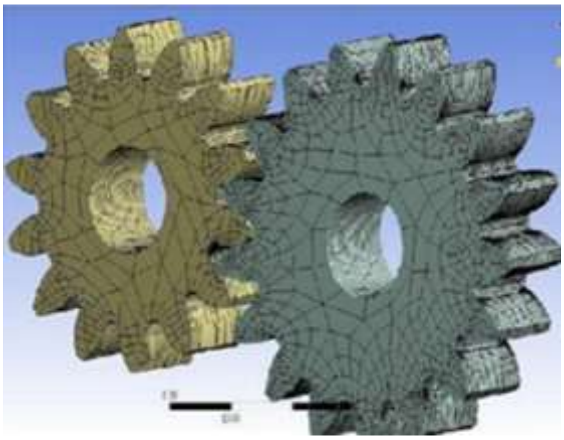


Fig. 10: symmetric gear pair under a mesh of hex-dominant

Bending stress

The following figures shows a symmetric spur gear under a bending stress on the tooth surface.

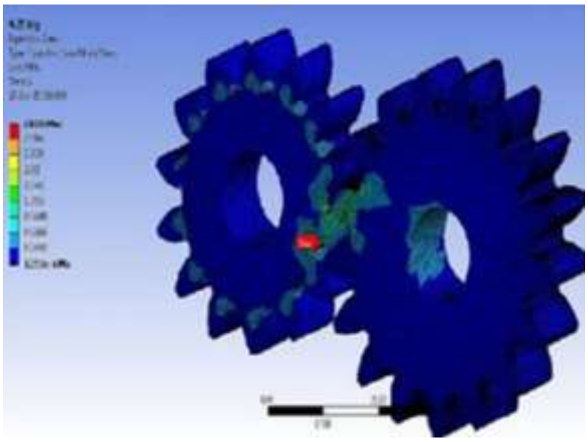


Fig. 11: metallic gear under bending stress

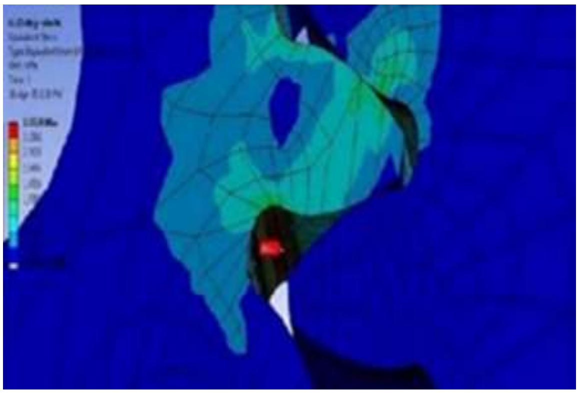


Fig.12: non-metallic gear under bending stress

Contact stress

The following figures shows that at the mating surface between the two gears a contact surface appears.

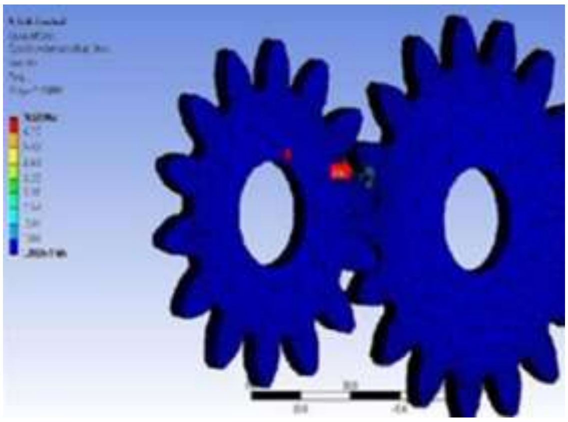


Fig.13: metallic gear under contact stress

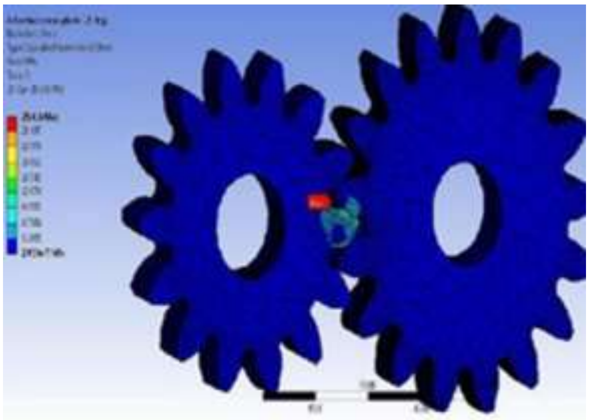


Fig. 14: non-metallic gear under contact stress

Table.4: Stress outcomes

Stress type	Metallic gear (MPa)	Non-metallic gear (MPa)
Contact stress	**70.6**	**29.4**
Bending stress	**2.8**	**3.6**

The outcome found from the examination draws briefly for both stress contact and bending for the gear pairs of metallic and non-metallic.

7.2. Design Specification

One of the simplest types of gears and used communally for most of the applications is spur gear. Spur gears are used for transmission of a rotational motions between many parallel shafts, also they are the best choice for many situations except ratio direct towards other choices, needs of high speeds and heavy loads. The spur gear usually selected in ratio range 1:1 or 1:6 with pitch line velocity up to 25 m/s, also the efficiency of the spur gear can be estimated till 98%-99% [10]. The material of the spur gear differs in its parts, for example the wheel is made of a thinner material than the pinion, the teeth number should be high in spur gears with normal pressure angle of 20 degrees is 18. Due to the ability of manufacturing it, the spur gears are used in many applications since they are simple in construction and cost less

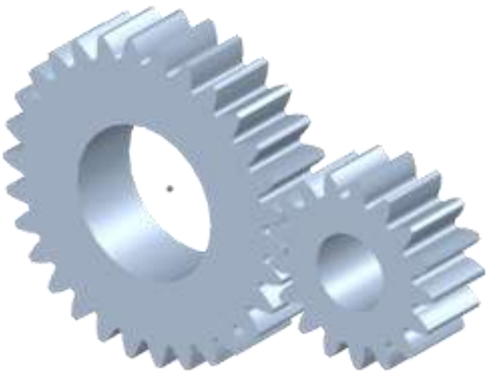


Fig.15: Spur gear.

The application of spur gears depends on reduce or increase the speed, torque multiplication, resolution and accuracy of positioning systems. The motion in spur gears are only transfer motion between parallel axis, and due to the motion mate only one tooth at time, a high stress on mating tooth occur and loudly operations. In our design the spur gear is used for solar applications.

Dimension Specifications

The geometry of tooth via gear mate can be specified in many ways:

Diametral pitch (DP): is the ratio number of teeth to pitch diameter of a gear [11]. Whenever the DP number was higher means finer spacing. It can be estimated by the formula:

$$\mathbf{DP} = (\mathbf{N+2}) \div \mathbf{OD} \quad (15)$$

Where N is the number of teeth, and OD represents the circumferential measurement.

Circular pitch (CP): is the direct measurement of the distance from one tooth centre to the adjacent tooth centre [12]. It can be measured by the formula:

$$\mathbf{CP} = \Pi \div \mathbf{DP} \quad (16)$$

Module (M): is a typical gear discipline and is a measurement of the size and teeth number of the gear [13]. We can obtain module by the formula:

$$\mathbf{M} = \mathbf{OD} \div \mathbf{N} \quad (17)$$

Pressure angle is the angle of tooth drive action, or the angle between the line of force between meshing teeth and the tangent to the pitch circle at the point of mesh [14]. Typical pressure angles are 14.5° or 20°.

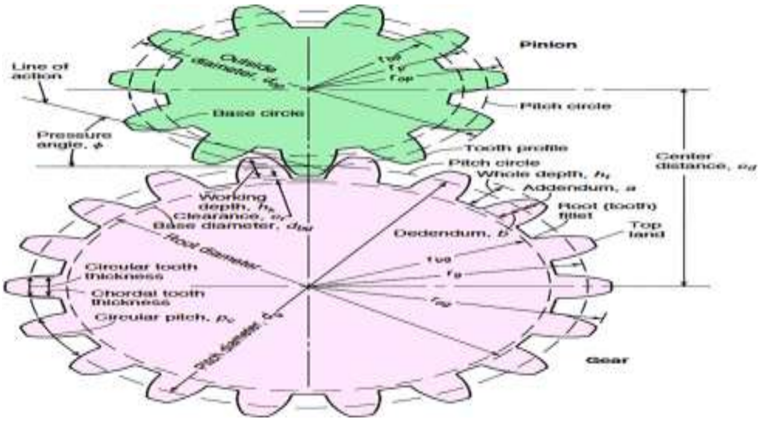


Fig.16: Pressure angle.

Determination of Number of Teeth – Interference

The aim of this part is determine the number of teeth on both parts. By assuming the number of teeth on the first gear (T1), using the formula giving below we can estimate the number of teeth on the second gear (T2).

$$T2 = \frac{T1}{Dp1} Dp2 \qquad (18)$$

So we got number of teeth on both the gears, but one should also check for a phenomenon called interference if gear system has to have a smooth operation. Interference happens when gear teeth has got profile below base circle [15]. This will result high noise and material removal problem. This phenomenon is shown in following figure.

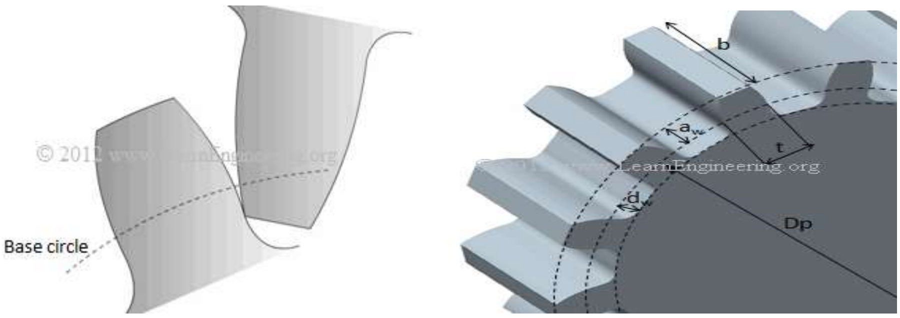


Fig. 17: A pair of gear teeth under interference

In order to reduce interference, the pinion must have a minimum number of teeth determined by following equation:

$$T_1 \geq \frac{2a_w \frac{1}{T_2} P_d}{\sqrt{1 + \frac{1}{T_2}\left(\frac{1}{T_2} + 2\right) sin^2\phi} - 1} \qquad (19)$$

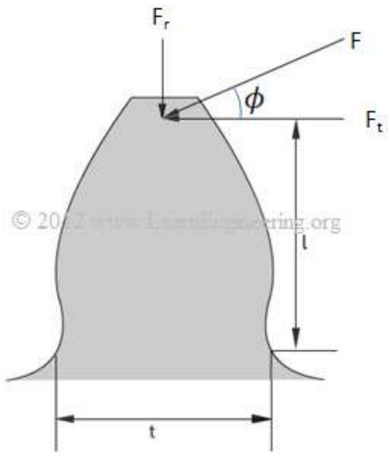
Where aw represents addendum of tooth. For 20-degree pressure angle (which is normally taken by designers) aw = 1 m and bw = 1.2 m [16].

Design for Mechanical Strength - Lewis Equation

the major parameter remaining in gear design is width of the gear teeth, b. This is determined by checking whether maximum bending stress induced by tangential component of transmitted load, Ft at the root of gear is greater than allowable stress [17]. As known, power transmitted, P and pitch line velocity V of the gear Ft can be obtained by:

F_t V = Power transmitted (20)

Here we consider gear tooth like a cantilever which is under static equilibrium. Gear forces and detailed geometry of the tooth is shown in figure below.



Fi. 18: Gear tooth under load.

One can easily find out maximum value of bending stress induced if all geometrical parameters shown in above figure are known. But the quantities t and l are not easy to determine, so we use an alternate approach to find out maximum bending stress value using Lewis approach. Maximum bending stress induced is given by Lewis bending equation as follows:

$$\sigma = \frac{\text{Ft Pd}}{bY} \quad (21)$$

Where Y is Lewis form factor, which is a function of pressure angle, number of teeth and addendum and dedendum. Value of Y is available as in form of table or graph [18].

A More Realistic Approach - AGMA Strength Equation

due to collision happening between gear teeth, we can hear noises due to small clearance in between them. Such collisions will add load on the gear more than the previously calculated value. This effect is incorporated in dynamic loading factor, Kv value of which is a function of pitch line velocity [19]. At root of the gear there could be fatigue failure due to stress concentration effect. Effect of which is incorporated in a factor called Kf value of which is more than 1. There will be factors to check for overload (Ko) and load distribution on gear tooth (Km) [20]. While incorporating all these factors Lewis strength equation will be modified like:

$$\sigma = \frac{F_t P_d}{bY} K_v K_o K_m K_f$$ (22)

The equation can also be represented in an alternating form (AGMA Strength equation) like:

$$\sigma = \frac{F_t P_d}{bJ} K_v K_o K_m$$
(23)

Where J can be obtained by:

$$J = \frac{Y}{Kf}$$
(24)

Using the equations mentioned above we can obtain the value of b, so all the expected parameters for gear design are obtained. However, the gears don't have a guarantee peaceful operations if it has high surface resistance.

Conclusion

In this project, The static stresses of the spur gear pairs were investigated using a finite element meshing simulation to determine the differences in stress results for various material types, including metallic (Iron, steel, bronze, and phenolic resins, AISI 4140, etc.)

We discovered that the stress values of both metallic and plastic gears have their advantages and disadvantages stresses. As a result, we concluded that all material type gear can be used in an environment where their setup and their parameters are installed, for them to reach their functions.

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