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Analysis of Design and Material Selection of a Spur gear pair for Solar Tracking Application*

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Abstract

The principal intentions of this paper are geometrical modelling and computational study of different static stresses on spur gears of different materials for an indigenous mechanical solar tracker. The analyzed static stress results of the symmetric type involute profiled gear pair are compared on the basis of the material and the best result is selected for the application in the tracker mechanism. Providing importance on the non- renewable energy sources, solar energy is the major primary source of energy which can satisfy the human needs for the future.

Gear operated mechanical Solar Tracking System is cheaper, require less skilled worker, easy to maintain and can be placed at hilly areas, remote or dusty or rainy place to help electrical power deficiency in rural areas and also can be installed easily in educational institutions, big offices, etc., which can save non-renewable sources of electrical energy for future use. The gears are one of the most imperative and crucial component in a mechanical power transmission unit, and its robustness led to the choice as mechanical component in the tracking mechanism. Since, the system is open to environment; therefore, the material selection of the gears becomes an important issue.

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1. Introduction

In order to reduce the cosine losses of the incident radiation on solar panels, different solar tracking mechanisms have been designed and implemented by various designers throughout the globe. Though, motor driven microprocessor controlled devices are mostly in use, but there are some disadvantages which could be overcome by using gear pair mechanisms in place of the former. The role of small spur gears for the accurate actuation for this purpose have paramount importance considering the cyclic dynamic and transient stresses built up in the tooth of the gear.

These are designed specifically for the particular function and applications. In case of dual axis tracking system for simultaneous rotation about a vertical and a horizontal axis and are usually driven by a pair of reversible motors. In this paper, a mechanical gear actuated solar tracking system has been proposed that uses a pair of involute spur gears, and for which the material selection is to be done. The gear pairs that are to be used is be of symmetric type involute profiled with standard 25° pressure angle. Gears vary from a tiny size in watches to the larger gears used in lifting machines. Gears consist of two forms of teeth, one is the cycloidal form and the other is the involute forms, and considered one of the most critical components in mechanical power transmission system. In this paper and application of the solar tracking mechanism, the involute form of teeth is taken into consideration because of the advantage the form of teeth has over the cycloidal one, which is, if the centre distance of any wheel (gear) changes or is being shifted, then also the involute profiled (formed) tooth will give constant velocity ratio which is not in case of the cycloidal profiled tooth. It is probable that gears may predominate as the most effective means of transmitting power in future machines because of their high degree of reliability and compactness. Also, the increasing demand for the quiet power transmission in machines has created a growing demand for more precise analysis of the gear system characteristics. It was founded that, spur gears with contact ratio more than 2 and pressure angle more than 20° work considerably quieter. The dynamic gear loads affect the gear vibrations, acoustic emission, tooth fatigue and surface failure. If the dynamic gear loads is minimized, it can result in the decrease of gear noise, increase gear efficiency, improve pitting fatigue life and also prevent gear tooth fracture [1]. Generally, changing of the pressure angle will impact the tooth mesh characteristics, such as tooth contact zone contact ratio. The static stress analyses, such as beam strength, bending strength, contact stress, of spur gears using Finite Element Method (FEM) was discussed [2], where, the step by step FEM was discussed and different gear calculations had been performed and a comparison was carried out between the numerically obtained and theoretically obtained values, concluding that both values were in good agreement.

FEM is capable of providing information on contact and bending stresses, transmission errors, etc., which are required for designing a robust and quiet gear pair system, but the time required to create such a model is quite large. Thus, to reduce the time required for modelling, the geometry needed for finite element analysis may be created using CAD/CAM/CAE software. Using the available advanced FEA software (ANSYS), a number of studies are now aimed at furthering the basic understanding of gears in mesh. This improved understanding of gear behaviour, such as, static stresses and deformations, will increase the ability of designers to design high performance transmission systems which meet the requirements in various operating conditions. The choice of material depends on the power to be transmitted and the running speed and the advantages of non-metallic gears were discussed [3].

Finite Element Analysis has advantages, such as, improved visualization, decreased cycle time, reduced number of prototypes, and reduced testing times, optimum design. A low profile tracker consisting of two coplanar and perpendicular linear actuators was coupled with a single linkage arm and pivots in order to pathway the sunrays incorporated in grid scale photo-voltaic facilities, resulting to near about 30% of energy production gains [4]. A model was proposed and a comparison between Mechanical Solar Tracking System and Electro-Mechanical Solar Tracking System was made, which shown that the mechanical tracking system consumes zero energy from the produced energy and thereby, increasing the overall efficiency [5]. The increase in the pressure angles in gear teeth, making the profile different, decreases or reduces the bending stress and also the contact stress [6].

Nomenclature

N_P and N_G	Number of teeth on Pinion and Gear
m	Module
p	Circular pitch
P	Diametral pitch
d'	Pitch circle diameter
d_a	Tip circle diameter
d_b	Base circle diameter
d_t	Root circle diameter
ϕ	Pressure Angle
h_a	Addendum
h_f	Dedendum
c	Clearance
h_t	Whole depth
h_k	Working depth
s	Tooth thickness on pitch circle
r_A	Addendum circle radius
α	Half angle of tooth
σ	Bending Stress on tooth fillet
T	Torque transmitted
B	Face width
y	Lewis form factor

2. Computational Procedure

Basic gear calculation formulae used for symmetric gears [7]:

1. Circular pitch, $p = \pi \cdot d' / N_P$
2. Diametral pitch, $P = N_P / d'$
3. Module, $m = 1/P$
4. Tip circle diameter, $d_a = d' + 2 \cdot m$
5. Root circle diameter, $d_t = d' - (2 \times 1.25 \cdot m)$
6. Base circle diameter, $d_b = d' \times \cos\phi$

7. Addendum, $h_a = m$
8. Dedendum, $h_f = 1.157 \cdot m$
9. Clearance, $c = 0.157 \cdot m$
10. Working depth, $h_k = 2 \cdot m$
11. Whole depth, $h_t = 2.157 \cdot m$
12. Tooth thickness on pitch circle, $s = (\pi \times m)/2$
13. Addendum circle radius, r_A = Pitch circle radius × Addendum

3. Gear material selection

Selection of material for the gear pair have become a very essential task for the mentioned application as the mechanism is open to the atmosphere. In view of the application of gear pairs, primarily two types of materials were chosen, viz., metals and plastics. After thorough literature survey, the following metals and plastic material pair are selected for this purpose, where, in both cases, the material for the smaller wheel are chosen of high hardness compared to that of the larger wheel; because the teeth of a pinion (smaller wheel) are more frequently stressed than the teeth of the mating gear (larger wheel) during the course of service, and in order to compensate rate of wear in the pinion [4]. Then, the material properties that are considered for input in the ANSYS for the analyses of the gear pairs (both metallic and plastic). The assigned properties of chosen materials for metallic gears are shown in table 1.

Table 1. Assigned properties of selected materials for gear

	ASTM Class 35 Cast Iron	**ASTM 1045 or C45 steel**
Young's Modulus (MPa)	1.14×10^5	2×10^5
Density (kg/m^3)	7150	7870
UTS (MPa)	252	565
Poisson's ratio	0.29	0.29
Yield Strength (MPa)	165	310
HB	200- 260	175-215

Considering the application of the gear pairs in the solar tracking, pair of non-metallic gears is also analyzed in the present work. The non-metallic (plastic) gears are suggested in order to use the advantages of the non-metallic gears that these have good operational properties and noiseless operation with low cost maintenance. The properties of the non-metals are shown in table 2.

Table 2. Assigned properties of selected non-materials for gear

	NYLON 6/6	**Polyphenylene Sulphide**
Density(ASTM test method- D792) (kg/m^3)	1140.412	1215.628
Rockwell Hardness (ASTM test method- D785)(J/m)	64.02	92-126
Tensile Strength (ASTM test method- D638) (N/mm^2)	85.517	649
Compressive Strength (ASTM test method- D695) (N/mm^2)	160	21500
Young's Modulus (N/mm^2)	7600	1.136×10^5
Poisson's Ratio	0.36	0.4
Bulk Modulus (N/mm^2)	9047.6	1.894×10^5
Shear Modulus (N/mm^2)	2794.1	40589

4. Results and illustrations

This section discusses about the three dimensional model of the gear and pinion in mesh and also the finite element method that has been used to analyse the static conditions and calculate analytically the maximum stresses when the spur gear are in contact for both symmetric and asymmetric mating spur gear arrangements.

The dimensions of the involute symmetric spur gear or the wheel and the pinion are presented in table 3.

Table 3. Parameter dimension

Parameters	Pinion	Gear
Gear Ratio	1	1.21
Module (in mm)	4	4
Number of Teeth	14	17

The 3D models of the pinion and the gear are created using CAD/CAM/CAE software and the analysis of the gear pair assembly was done using finite element based software, ANSYS 14. The correct finite element meshing is required for obtaining result close to accuracy in the finite element methods [8].

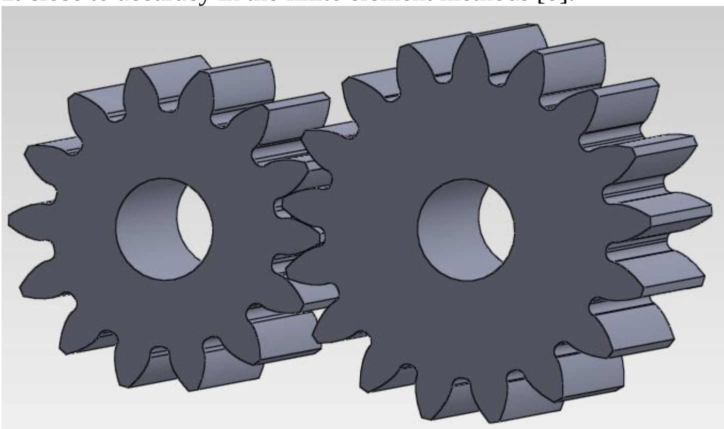
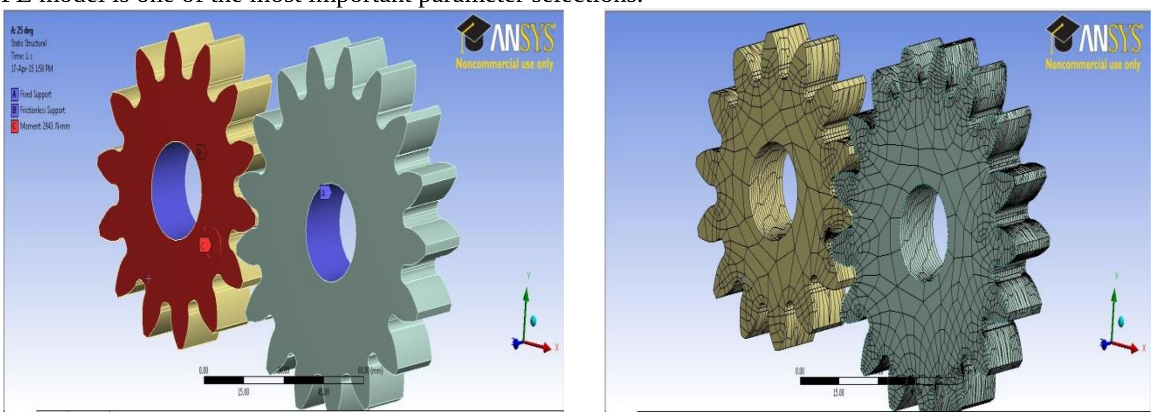


Fig. 1. Assembled solid model of 25° Involute Spur gear pair

The Hex-dominant meshing has been used for the symmetric gear pair. The type of the element(s) that are chosen in a FE model is one of the most important parameter selections.



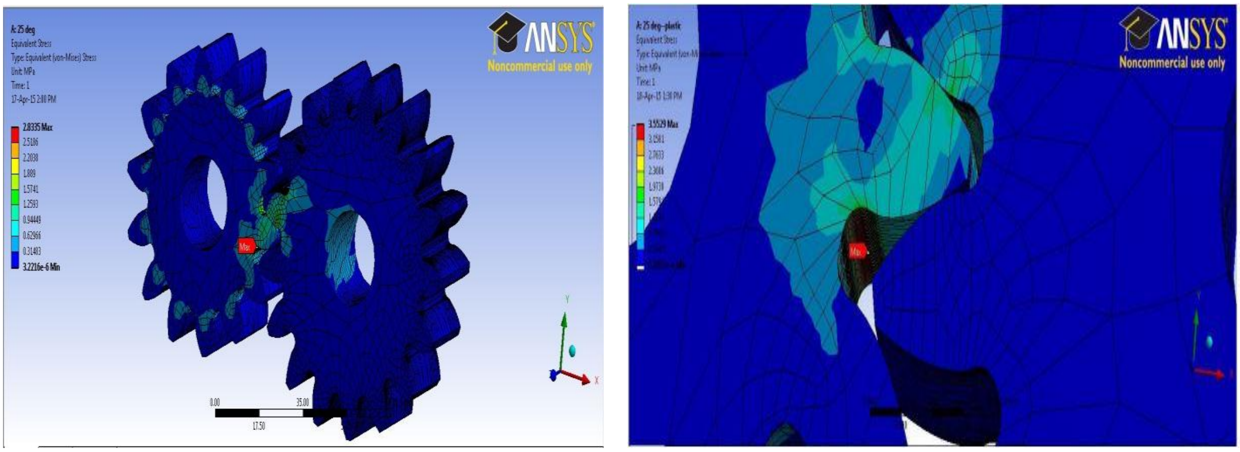
a b

Fig. 2. (a) Boundary Conditions; (b) FE Mesh.

For this particular problem, since the gear is a complicated model, the hex-dominant (commonly known as hexa-hedron) meshing type is chosen. The hex-dominant or hexahedron meshing has higher degree of freedom of element that may yield smooth node distribution and also high accuracy [8].

4.1. Bending Stress

The bending stress for the symmetric spur gear pair is on the tooth fillet region as the pinion and the wheel act as a cantilever beam with load on its free end [9].

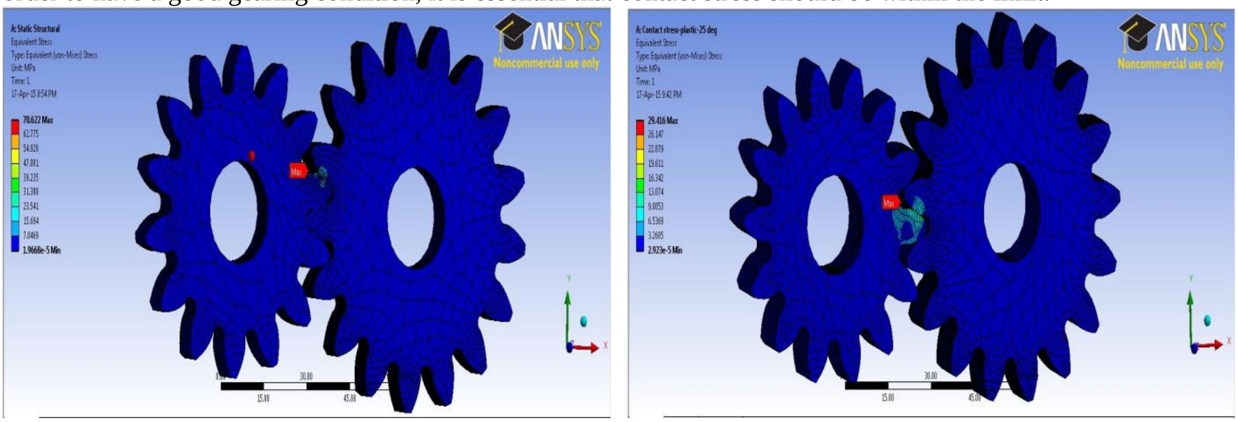


a b

Fig. 3. (a) Metallic gear pair; (b) Plastic gear pair

4.2. Contact Stress

The contact stress on gears occurs at the mating faces of the two gears (pinion and wheel) in mating condition. In order to have a good gearing condition, it is essential that contact stress should be within the limit.



a b

Fig. 4. (a) Metallic gear pair; (b) Plastic gear pair

Table 4. Stress Results

Stress type	Metallic gear pair (MPa)	Plastic gear pair (MPa)
Bending Stress	2.8335	3.5553
Contact Stress	70.675	29.416

The results obtained from the analyses show that the bending and contact stresses for gear pair of both the material type are far below their respective permissible stress values as shown in table 4.

5. Conclusion

In this paper, the static stresses, i.e., Bending and Contact stresses of the 25° involute profiled spur gear pairs were studied through finite element meshing simulation for finding out the differences in stress results for the various material types, viz., metallic (ASTM Class 35 Cast Iron and ASTM 1045 or C45 steel) and plastic (NYLON 6/6 and Polyphenylene Sulphide). It is found out that both metallic and plastic gears have their stress values far below their permissible stress limits, and also, the stresses induced in both the gear pairs are close enough. Thus, it can be concluded that for an open environment wherein the mentioned setup is to be installed, both material type gear pairs may be applied.

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