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Analysis of Spur Gear Using Composite Material

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Abstract: Spur gears are the simplest and widely used in power transmission. In recent years it is required to operate machines at varying load and speed. Gear teeth normally fail when load is increased above certain limit. Therefore, it is required to explore alternate materials for gear manufacturing.
Composite materials provide adequate strength with weight reduction and they have emerged as a better alternative for replacing metallic gears. Composites provide much improved mechanical properties such as better strength to weight ratio, more hardness, and hence less chances of failure. So, this work is concerned with replacing metallic gear with composite material to improve performance of machine and to have longer working life. Efforts have also been carried out for modeling using 3D modelling software called SOLIDWORKS and finite element analysis of gears using ANSYS.
Composite gears have been manufactured by stir casting, which is economical method. Composite gears offer improved properties over steel alloys and these can be used as better alternative for replacing metallic gears.

I. INTRODUCTION

Gearing is one of the most critical components in a mechanical power transmission system, and in most industrial rotating machinery. It is possible that gears will predominate as the most effective means of transmitting power in future machines due to their high degree of reliability and compactness. In addition, the rapid shift in the industry from heavy industries such as shipbuilding to industries such as automobile manufacture and office automation tools will necessitate a refined application of gear technology.

A gearbox as usually used in the transmission system is also called a speed reducer, gear head, gear reducer etc. which consists of a set of gears, shafts and bearings that are factory mounted in an enclosed lubricated housing. Speed reducers are available in a broad range of sizes, capacities and speed ratios. Their job is to convert the input provided by a prime mover (usually an electric motor) into an output with lower speed and correspondingly higher torque. In this thesis, analysis of the characteristics of involutes spur gears in a gearbox was studied using nonlinear FEM.

The increasing demand for quiet power transmission in machines, vehicles, elevators and generators, has created a growing demand for a more precise analysis of the characteristics of gear systems. In the automobile industry, the largest manufacturer of gears, higher reliability and lighter weight gears are necessary as lighter automobiles continue to be in demand. In addition, the success in engine noise reduction promotes the production of quieter gear pairs for further noise reduction. Noise reduction in gear pairs is especially critical in the rapidly growing field of office-automation equipment as the office environment is adversely affected by noise, and machines are playing an ever-widening role in that environment. Ultimately, the only effective way to achieve gear noise reduction is to reduce the vibration associated with them. The reduction of noise through vibration control can only be achieved through research efforts by specialists in the field. However, a shortage of these specialists exists in the newer, lightweight industries in Japan mainly because fewer young people are specializing in gear technology today and traditionally the specialists employed in heavy industries tend to stay where they are.

A. Gear

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part to transmit torque. Geared devices can change the speed, torque, and direction of a power source. Gears almost always produce a change in torque, creating a mechanical advantage, through their gear ratio, and thus may be considered a simple machine. The teeth on the two meshing gears all have the same shape. Two or more meshing gears, working in a sequence, are called a gear train or a transmission. A gear can mesh with a linear toothed part, called a rack, thereby producing translation instead of rotation. The gears in a transmission are analogous to the wheels in a crossed belt pulley system. An advantage of gears is that the teeth of a gear prevent slippage.

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When two gears mesh, if one gear is bigger than the other, a mechanical advantage is produced, with the rotational speed, and the torques, of the two gears differing in proportion to their diameters. In transmissions with multiple gear ratios such as bicycles, motorcycles, and cars the term "gear" as in "first gear" refers to a gear ratio rather than an actual physical gear. The term describes similar devices, even when the gear ratio is continuous rather than discrete, or when the device does not actually contain gears, as in a continuously variable transmission.

B. Types of Gear

1) External VS Internal Gears

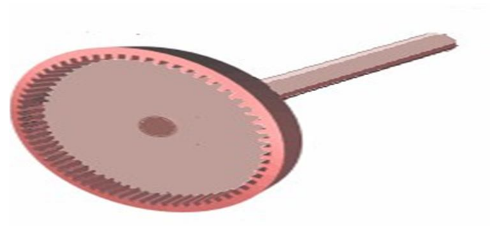

FIG 1 EXTERNAL VS INTERNAL GEARS

An external gear is one with the teeth formed on the outer surface of a cylinder or cone. Conversely, an internal gear is one with the teeth formed on the inner surface of a cylinder or cone. For bevels gears, an internal gear is one with the pitch angle exceeding 90 degrees. Internal gears do not cause output shaft direction reversal.

2) Helical Gears

Helical or "dry fixed" gears offer a refinement over spur gears. The leading edges of the teeth are not parallel to the axis of rotation, but are set at an angle. Since the gear is curved, this angling makes the tooth shape a segment of a helix. Helical gears can be meshed in parallel or crossed orientations. The former refers to when the shafts are parallel to each other; this is the most common orientation. In the latter, the shafts are non-parallel, and in this configuration the gears are sometimes known as "skewgears".

Fig 2 Helical Gear

The angled teeth engage more gradually than do spur gear teeth, causing them to run more smoothly and quietly. With parallel helical gears, each pair of teeth first make contact at a single point at one side of the gear wheel; a moving curve of contact then grows gradually across the tooth face to a maximum then recedes until the teeth break contact at a single point on the opposite side. In spur gears, teeth suddenly meet at a line contact across their entire width causing stress and noise. Spur gears make a characteristic whine at high speeds. For this reason spur gears are used in low speed applications and in situations where noise control is not a problem and helical gears are used in high speed applications, large power transmission, or where noise abetment is important. The speed is considered high when the pitch line velocity exceeds 25 m/s.

3) Bevel Gear

A bevel gear is shaped like a right circular cone with most of its tip cut off. When two bevel gears mesh, their imaginary vertices must occupy the same point. Their shaft axes also intersect at this point, forming an arbitrary non-straight angle between the shafts. The angle between the shafts can be anything except zero or 180 degrees. Bevel gears with equal numbers of teeth and shaft axes at 90 degrees are called miter gears.

4) Worm Gear

Fig 3 Worm Gear

A worm is meshed with a worm wheel, which looks similar to a spur gear. Worm-and- gear sets are a simple and compact way to achieve a high torque, low speed gear ratio. For example, helical gears are normally limited to gear ratios of less than 10:1 while worm-and-gear sets vary from 10:1 to 500:1. A disadvantage is the potential for considerable sliding action, leading to low efficiency. A worm gear is a species of helical gear, but its helix angle is usually somewhat large (close to 90 degrees) and its body is usually fairly long in the axial direction. These attributes give it screw like qualities. The distinction between a worm and a helical gear is that at least one tooth persists for a full rotation around the helix. If this occurs, it is a 'worm'; if not, it is a 'helical gear'. A worm may have as few as one tooth. If that tooth persists for several turns around the helix, the worm appears, superficially, to have more than one tooth, but what one in fact sees is the same tooth reappearing at intervals along the length of the worm. The usual screw nomenclature applies: a one-toothed worm is called single thread or single start; a worm with more than one tooth is called multiple threads or multiple starts. The helix angle of a worm is not usually specified. Instead, the lead angle, which is equal to 90 degrees minus the helix angle, is given. In a worm-and- gear set, the worm can always drive the gear. However, if the gear attempts to drive the worm, it may or may not succeed. Particularly if the lead angle is small, the gear's teeth may simply lock against the worm's teeth, because the force component circumferential to the worm is not sufficient to overcome friction.

II. GEAR MATERIALS

A. Structural Steel

Structural steel is a material used for steel construction, which is formed with a specific shape following certain standards of chemical composition and strength. They can also be defined as hot rolled products, with a cross section of special form like angles, channels and beams/joints. There has been an increasing demand for structural steel for construction purposes in the United States and India. Measures are been taken by the structural steel authority for ready availability of structural steel on time for the various projects. The people at every level are working hard to realize the purpose of producing steel on time, like, service centers, producers, fabricators and erectors along with the general contractors, engineers and architects are all working hand in hand. Steel has always been more preferred to concrete because steel offers better tension and compression thus resulting in lighter construction. Usually structural steel uses three dimensional trusses hence making it larger than its concrete counterpart. There are different new techniques which Design of steel structures.

B. Composite Material

Carbon Fiber The principal purpose of the reinforcement is to provide superior levels of strength and stiffness to the composite. In a continuous fiber- reinforced composite, the fibers provide virtually all of the strength and stiffness. Even in particle reinforced composites, significant improvements are obtained. Carbon fibers display linear stress-strain behavior to failure, the increase in strength also means an increase in the elongation-to-failure. The commercial fibers thus display elongations of up to 2.2%, which means that they exceed the strain capabilities of conventional organic matrices. Carbon fibers are available from a number of domestic and foreign manufacturers in a wide range of forms having an even wider range of mechanical properties. The earliest commercially available carbon fibers were produced by thermal decomposition of rayon precursor materials. The process involved highly controlled steps of heat treatment and tension to form the appropriately ordered carbon structure. Carbon fibers are also manufactured from pitch precursor for specialty applications. Pitch fiber properties typically include high modulus and thermal conductivity.

C. *Epoxy Resin*

Epoxy resins are widely used in filament-wound composites and are suitable for molding prepress. They are reasonably stable to chemical attacks and are excellent adherents having slow shrinkage during curing and no emission of volatile gases. These advantages, however, make the use of epoxies rather expensive. Also, they cannot be expected beyond a temperature of 140ºC. Their use in high technology areas where service temperatures are higher, as a result, is ruled out. Epoxy-reinforced concrete and glass-reinforced and carbon-reinforced epoxy structures are used in building and bridge structures. The applications for epoxy-based materials are extensive and include coatings, adhesives and composite materials such as those using carbon fiber and fiberglass reinforcements. The chemistry of epoxies and the range of commercially available variations allow cure polymers to be produced with a very broad range of properties. In general, epoxies are known for their excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties. Epoxy is a copolymer that is; it is formed from two different chemicals. These are referred to as the resin‖ or compound‖ and the hardener or activator the resin consists of monomers or short chain polymers with an epoxide group at either end. Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A. Two part epoxy coatings were developed for heavy duty service on metal substrates and use less energy than heat-cured powder coatings. Their low volatility and water cleanup makes them useful for factory cast iron, cast steel, cast aluminums applications and reduces exposure and flammability issues associated with solvent-borne coatings. They are usually used in industrial and automotive applications since they are more heat resistant than latex-based and alkyd- based paints. The large family of epoxy resins represents some of the highest performance resins of those available at this time. Epoxies generally out-perform most other resin types in terms of mechanical properties and resistance to environmental degradation, which leads to their almost exclusive use in aircraft components. As a laminating resin their increased adhesive properties and resistance to water degradation make these resins ideal for use in applications such as boat building. Here epoxies are widely used as a primary construction material for high-performance boats or as a secondary application to sheath a hull or replace water-degraded polyester resins and gel coats.

III. AIM AND OBJECTIVE OF RESEARCH

The purpose of this project is to study the effect of change of material in spur gear when composite material is used in place of structural steel. The objectives of this project are:-

1) Analyze the change in stresse of the both structural steel and composite material spur gear.
2) To Analyze the change in other properties and terms of both material spur gear.

IV. PROJECT METHODOLY

1) Study of Research Material
2) Literature review
3) Material selection
4) Development of Composite Material Spur Gear
5) Cad Modeling
6) Finite Element Analysis
7) Analysis with Ansys v15.0
8) Comparison of Analysis Result
9) Ergonomics Details
10) Future scope in Designs for Composite Material Spur Gear**.**

V. CALCULATIONS OF VARIOUS GEAR AND PINION MODELS

ANALYSIS WITH DIFFERENT MODULE & LOADS (MODEL - APPLE PILLER)

A. *For Module= 3 MM*

Tp= 21,

t_g= 42,

h=0.25×3,

b_p= 32 mm,

b_g=32mm,

Tangent load=2500 N,
E=2e11,
μ= 0.3,
d_p= 63mm,
d_g=126 mm
FOR PINION & GEAR

1) Width of Narrow Rectangular pressure distribution

$$= \frac{\sqrt{2F\frac{(1-V1^2)}{E1}+\frac{(1-V2^2)}{E2}}}{\pi L\left(\frac{1}{d1}+\frac{1}{d2}\right)}$$

= (t)
= 1.38e-4 mm

2) Contact Pressure Pmax= 2×F/(pi×t×b)= 371163.58 N/mm2 = 371163.58 Mpa
3) Hertz Stress (Fh)=Pmax = 371163.58 Mpa
4) Von mises Stress = 0.57×fh =211562.91 Mpa
5) Max shear stress = 0.30× fh= 111349.07 Mpa
6) Ortho shear stress= 0.25×fh= 92790.895 Mpa

B. For Module= 3.5 MM

Tp= 21,
tg= 42
b_p=32 mm,
b_g= 32 mm,
Tangent load=2500 N,
E=2e11,
μ= 0.3,
d_p=73.5mm,
d_g=147 mm

FOR PINION & GEAR

1) Width of Narrow Rectangular pressure distribution

$$= \frac{\sqrt{2F\frac{(1-V1^2)}{E1}+\frac{(1-V2^2)}{E2}}}{\pi L\left(\frac{1}{d1}+\frac{1}{d2}\right)}$$

= (t)
= 1.489e-4 mm

2) Contact Pressure Pmax= 2×F/(pi×t×b)= 333962.35 N/mm2 = 333962.35 Mpa
3) Hertz Stress (Fh)=Pmax = 333962.35 Mpa
4) Von mises Stress = 0.57×fh =109358.54 Mpa
5) Max shear stress = 0.30× fh= 100188.70 Mpa
6) Ortho shear stress= 0.25×fh= 83490.588 Mpa

VI. ANALYSIS RESULTS

Applying Module of 3 mm and 3.5 mm with Analysis result of Structural steel spur gear and Composite materials spur gear (Carbon fiber and epoxy resins) and then behavior of each element is analyzed with different material properties.

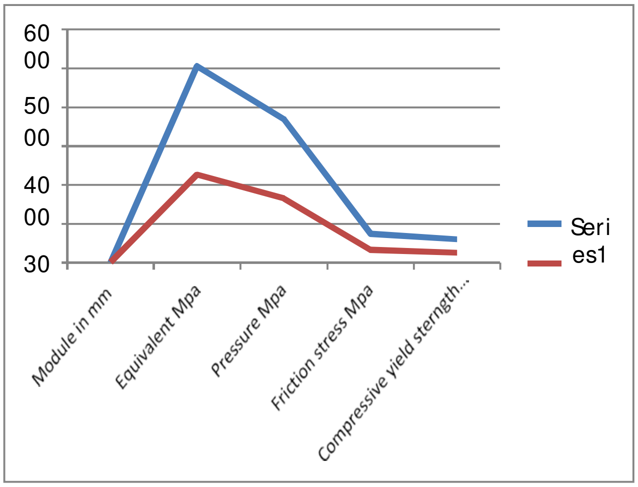

Table 1 Analysis Result of Structural Steel Spur Gear

Module in mm	Equivalent (Von-Mises) Stress(Max.) MPa	Pressure (Max.) Mpa	Friction Stress (Max.) MPa	Compreesive yieldstrength Mpa
3.0	2689.1	1837.9	367.57	250
3.5	2266.2	1644.8	328.95	250

Table 2 Analysis Result of Composite Materials Spur Gear (Carbon Fiber And EpoxyResins)

Module in mm	Equivalent (Von-Mises) Stress(Max.) MPa	Pressure (Max.) Mpa	Friction Stress (Max.) MPa	Compreesive yieldstrength Mpa
3.0	6050.5	4135.2	827.04	600
3.5	5085.9	3697.1	739.42	600

VII. CONCLUSION

From the above result formulated from simulation and analysis of structural steel and composite material i.e. carbon fiber and epoxy resin composite for the spur gear material in apple piller the following conclusion has been made:

1) as the density of composite of carbon fiber and epoxy resin is less than structural steel near about 75% that gives extreme weight reduction in case of compositematerial we shown effective result in power transmission.
2) From the properties it also seen that compressive strength of composite material is greater than structural steel near about 50% means composite material sustain against more compressive stress.
3) from the table it also seen that pressure sustainability in composite material is more means in the structural steel maximum pressure sustainable is found to be 1897.9 mpa while in composite material of carbon fiber and epoxy resins is found to be more i.e. maximum limit is 4135.28mpa
4) The stresses generated in composite material also seen to be more in composite material i.e. composite material is more reliable for the higher stress generated during working of spur gear than structural steel spur gear material.
5) But there is a small drawback in case of frictional stress which produced more stress in composite material than structural steel which wear and tear losses but it not affects that much.
6) Form above the conclusion it seems that carbon fiber and epoxy resins is a better alterative than the structural steel to replace as a spur gear material.

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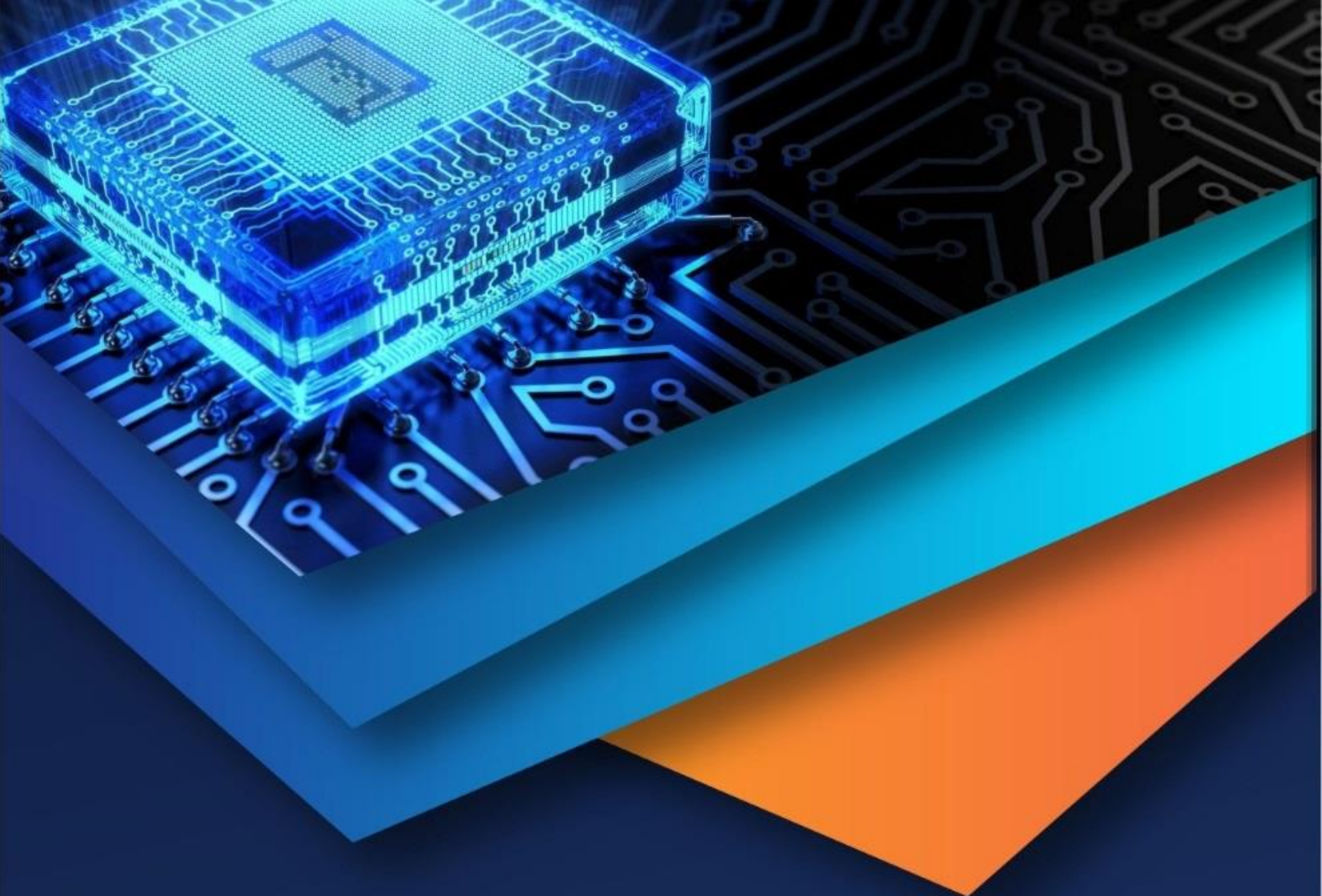

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