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Design and Contact Analysis of Plastic Spur Gears Using Finite Element Analysis

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Abstract - The aim of this project to evaluate the contact stress of plastic material in gear for heavy duty loading condition. Plastic gears have good qualities like self-lubrication, low density, corrosion resistance and smooth running besides its lower strength. Plastic materials provide adequate strength with weight reduction and they are emerging as a better alternative for replacing metallic gears. In this work Poly Ether Ether Ketone (PEEK) material is used. These plastic materials have semi crystalline thermo plastic with excellent mechanical and chemical resistance properties that are retained to high temperatures. An APDL gear model has been developed for the design evaluation and comparison study. Gear design parameter like module, face width and pitch circle radius etc can be varied to optimize the design parameter in the geared APDL model to make plastics as feasible gear model. The contact stress of plastic spur gears are calculated by Finite Element Analysis using FEA software ANSYS 13.0.Contact Stress of plastic gears was analysed in this project.

Index Terms – Plastics Spur gear, PEEK material, ANSYS APDL, Contact Stress, Finite Element Analysis.

I. INTRODUCTION

The spur gears when in action, are subjected to several stresses but out of all, two types of stresses viz., bending stress and contact stress are important from the design point of view. The bending stresses are theoretically analysed by Lewis equation and contact stresses by Hertz equation. Since spur gears have complicated geometry, a need arises for improved analysis using numerical methods which provide more accurate solutions than the theoretical methods. Finite Element Analysis is one such method which has been extensively used in analysis of components used in various mechanical systems.

PEEKis high temperature thermoplastic that is very resistant to chemical and fatigue environments and has very good thermal stability. PEEK is an excellent material for large array of thermal plastic applicatons where combustion, thermal, and chemical performance is critical. Peek exhibits a high ability to retain flexural and tensile properties at very high temperature 250C or more within steam, or high water pressure environments. Peek is inert to all common organic and inorganic liquids and common solvents. Peek can be manufactured as a composite or with fibre glass or carbon fibre reinforcements to enhance mechanical and thermal properties of the material. Peek is an excellent dielectric with low loss throughout high temperature and frequencies ranges. Other characteristics are:

1. Outstanding wear and abrasion resistance
2. Low coefficient of friction
3. High limiting PV properties
4. Low smoke and toxic gas emissions
5.Similarchemical and water resistance as PPS (polyphenylene sulfide), however has greater high temperature resistance.

PEEK Applications:

Automotive, Marine, Oil and petroleum environments, Electronics, Medical, Aerospace, General industrial

R. Yakut et al. The purpose of the paper is to examine the load capacity of PC/ABS spur gears and investigation of gear damage. Further in this study usability of PC/ABScomposite plastic material as spur gear was investigatedand was defined that PC/ABS gears were tested by applyingthree different loading at two different numbers of revolutionson the FZG experiment set. The experiment resultsummarized that the usage of PC/ABS materials brings anadvantage in many industrial area because such materials are durable against flame, air, ultraviolet lightsand holding lower moister than PA66 GFR 30 materials.The another result of this study was that good operatingcondition are comprised at low numbers of revolution andthe tooth loads. Further the suitable environmental conditionmust be revolutions and the tooth load for gears. PC/ABS gear should be preferred at low tooth and unwantedhigh power transmission.[1]

V. Siva Prasad et al. This paper describes design and analysisof spur gear and it is proposed to substitute the metallic gears of sugarcane juice machine with polymer gears to reduce the weight and noise. A virtual model of spur gear was created in PRO-E, Model is imported in ANSYS 10.0 for analysis by applying normal load condition. The main purpose of this paper to analysis the different polymergears namely nylon, polycarbonate and their viability checked with counterpart metallic gear like as cast iron.Concluding the study using the FEA methodology, it canbe proved that the composite gears, if well designed andanalysed, will give the useful properties like as a low cost,noise, Weight, vibration and perform its operation similarto the metallic gears. Based on the static analysis Nylongear are suitable for the application

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of sugarcane juice machine under limited load condition in comparison with castiron spur gears.[2]

Vivek Karaveer et al. This paper presents the stress analysisof mating teeth of the spur gear to find maximum contactstress in the gear tooth. The results obtained from finite elementanalysis are compared with theoretical Hertz equation values. The spur gear are modelled and assembled in ANSYS DESIGN MODELER and stress analysis of Spur geartooth is done by the ANSYS 14.5 software. It was foundthat the results from both Hertz equation and Finite Element Analysis are comparable. From the deformation pattern of steel and grey cast iron, it could be concluded that difference between the maximum values of steel and greyCI gear deformation is very less.[3]

Mahebub Vohra et al. In this paper, Metallic material Castiron and Non Metallic material Nylon are investigated. Thestress analysis of the lathe machine headstock gear box are analyzed by finite element analysis. Analytical bending stress is calculate by two formula Lewis formula and AGMAformula. Analytical results is compared with the finite elementmethod result for validation. Concluding the study, we observed that finite element method software ANSYS have values of stress distribution were in good agreement with the theoretical results. Besides non-metallic material can be used instead of metallic material because non-metallic material provide extra benefits like as less cost, self-lubricating, low noise, low vibration and easy manufacturing.[4]

M. Patil et al. The objective of this paper is to study thefree vibration behaviour of composite spur gear using finiteelement method which is also known as first order shear deformation plate theory (FSDT). The finite elementanalysis has been carried out for composite gear as a 4 nodded and 8 nodded quadrilateral element with each nodes has five degree of freedom. Finite element formulation of composite gear is modelled and coded using MATLAB.Based on the numerical analysis which is carried out for of spur gear the following important conclusion can be drawn. The developed MATLAB code is validated with theavailable result and it can be concluded that the present FE code result are in good agreement with those of reference.Fundamental frequencies obtained for composite spur gear using MATLAB are presented. It is found thatnatural frequency increases with increase in fibre orientation.[5]

II. MATERIAL PROPERTIES

The material chosen for the study is Plastics. Table 1 shows the properties of PEEK material as presented in ANSYS APDL 13.0 engineering data sources.

Table 1: Properties of PEEK material

S. No.	Material Property	Value	Unit
1	Density	1300	Kg/m3
2	Young's modulus	3.76E+9	pa
3	Poison's ratio	0.37	
4	Bulk modulus	5.74E+9	pa
5	Shear modulus	1.42E+9	pa
6	Tensile yield strength	100E+6	pa
7	Compressive yield strength	130E+6	pa
8	Coefficient of friction	0.18	
9	Thermal conductivity	0.25	W/m k
10	Coefficient of thermal expansion	47E-6	K-1
11	Specific heat	1501	J/kg K
12	Endurance limit	41.2E+6	pa

III. PARAMETRIC MODELLING OF SPUR GEAR

The spur gear is sketched and modelled in ANSYS APDL 13.0. The dimensions of the gear set are given in table 2. The values are same for both gears in assembly.

Table 2:Dimensions of the Spur Gears

S. No.	Description	Symbol	Value	Units
1	Module	m	2.5	mm
2	Pressure Angle	ϕ	20	°
3	No of teeth	Z	60	
4	Center distance	a	150	mm
5	Face width	b	25	mm
6	Pitch Circle Diameter	dp	150	mm
7	Base Circle Radius	rb	70.47	mm
8	Addendum Circle Radius	ra	77.5	mm
9	Dedendum Circle Radius	rd	71.8	mm
10	Addendum	ha	2.5	mm
11	Dedendum	hd	2.89	mm
12	Fillet Radius	rp	0.98	mm
13	Shaft Radius	rs	16	mm
14	Total angle	Ta	360	°
15	Bottom clearance	c	0.25	

Spur Gear Model Three Teeth:

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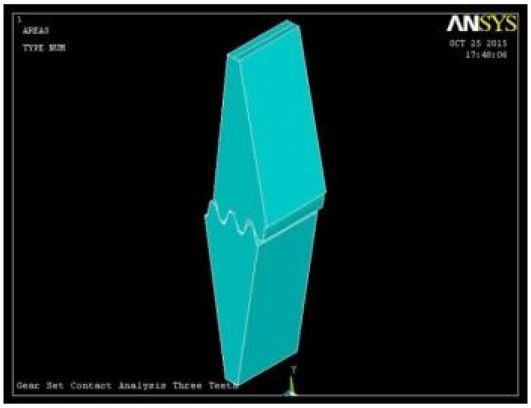

Figure 1: Three Dimensional Model of Spur Gear

Parametric modeling allows the design engineer to let the characteristic parameters of a product drive the design of that product. During the gear design, the main parameters that would describe the designed gear such as module, pressure angle, root radius, and tooth thickness, number of teeth could be used as the parameters to define the gear. But, the parameters do not have to be only geometric. They can also be key processinformation such as case hardening specifications, Quality of grades, metallurgical properties and even load classifications for the gear being designed. In this paper work module, pressure angle, numbers of teeth of Spur pinion and numbers of teeth Spur gear are taken as input parameters. Ansys uses these parameters, in combination with its features to generate the geometry of the Spur gear and all essential information to create the model. By using the relational equation in Ansys APDL, the accurate three dimensional Spur gear model is developed. The parametrical process can increase design accuracy, reduce lead times and improve overall engineering productivity.

IV. SPUR GEAR DESIGN

Design Calculation of Plastic Spur Gear:
Specifications of gear:

Module (m)	=	2.5 mm
Center distance (a)	=	150 mm
Pressure angle (α)	=	20 degree
Power (P)	=	2.25 Kw
Speed (N)	=	750 rpm

Design Calculation:

Power (P) = 2*π*N*T / 60
2250 = (2*π*750*T) / 60
T = (2250*60)/ (2*π*750)
Torque = 28.64788 N-m
Torque T = F * (d/2)
Force F = T/ (d/2)
= 28.64788/0.075
Force F = 381.97185 N

Calculation of tangential load:

$$F_t = \frac{P}{V} * K_o$$

Where, P= power
v= pitch line velocity
K_o= Service factor= 1.25 (medium)

$$V = \frac{\pi * D_1 * N_1}{60}$$

$$V = \frac{\pi * m * 60 * 750}{60 * 1000}$$

v = 2.356m m/s

$$F_t = \frac{2.25 * 1000}{2.356m} * 1.25$$

$$F_t = \frac{1193.761}{m}$$

Calculation of initial dynamic load:

$$F_d = F_t * C_v$$

C_v= Velocity factor

$$C_v = \frac{1 + v_m}{1 + 0.25 v_m}$$

$$C_v = \frac{1 + 12}{1 + 0.25 * 12}$$

C_v= 3.250

$$F_d = \frac{1193.761}{m} * 3.250$$

$$F_d = \frac{3879.722}{m}$$

Calculation of beam strength:

$$F_s = \pi m\, b\, \sigma_b\, y$$

Face width b = 10m
Allowable static stress σ_b = 58.86 N/m^2
Form factor = y

$$y = 0.154 - \frac{0.912}{z}$$

y = 0.139

F_s=π *m* 10m* 58.86* 0.139

F_s=257.031m^2

Calculation of module:

$$F_s \geq F_d$$

$$257.031\ m^2 \geq \frac{3879.722}{m}$$

m^3 = 15.094
m = 2.471

Take higher standard module m = 2.5
Then,

Face width b = 10m = 25mm

Pitch circle diameter d_1= m *z_1= 150mm

Pitch line velocity v = 5.890 m/s

Recalculation of beam strength:

$$F_s = \pi m\, b\, \sigma_b\ y$$

$$F_s = \pi * 2.5 * 25 * 58.86 * 0.139$$

$$F_s = 1606.44\ \text{N}$$

Calculation of accurate dynamic load:

$$F_d = F_t * C_v$$

$$F_t = \frac{P}{V} = \frac{2.25 * 1000}{5.890}$$

$$F_t = 381.97\ \text{N}$$

$$C_v = \frac{1 + v}{1 + 0.25v}$$

$$C_v = \frac{1 + 5.890}{1 + 0.25 * 5.890}$$

$$C_v = 2.787$$

$$F_d = 381.97 * 2.787$$

$$F_d = 1064.51\ \text{N}$$

Check for beam strength (tooth breakage):

$$F_s > F_d$$

1606.44> 1064.51

The design is safe.

Calculation of wear load:

$$F_w = d_1 * b * Q * k_w$$

Q = Ratio factor

$$Q = \frac{2i}{i + 1}$$

$$Q = \frac{2 * 1}{1 + 1}$$

Q = 1

k_w =Load stress factor =1.4 N/m^2(For non-metallic gear)

$$F_w = 150*25*1*1.4$$

$$F_w = 5250\ \text{N}$$

Check for wear:

$$F_w > F_d$$

5250> 1064.51

The design is Safe.

Safe for surface durability.

V. FINITE ELEMENT ANALYSIS USING ANSYS APDL 13.0

Finite Element Analysis is the practical application of the finite element method (FEM), which is used by engineers and scientists to mathematically model and numerically solve very complex structural, fluid, and multiphysics problems. FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.

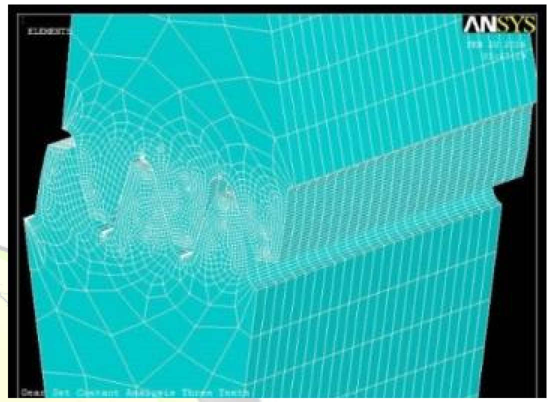

Figure 2: Meshing of spur gear

There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively. Within each of these modeling schemes, the programmer can insert numerous algorithms which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture.

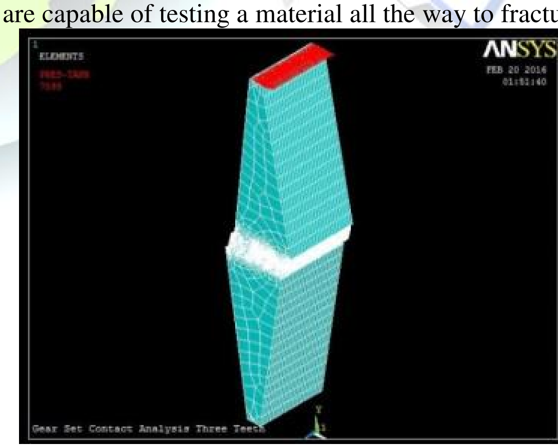

Figure 3: Boundary conditions of spur gear

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The loading conditions are assumed to be static. Load applied at rotational pressure inside driving gear rim and DOF applied at driven pinion inside rim.

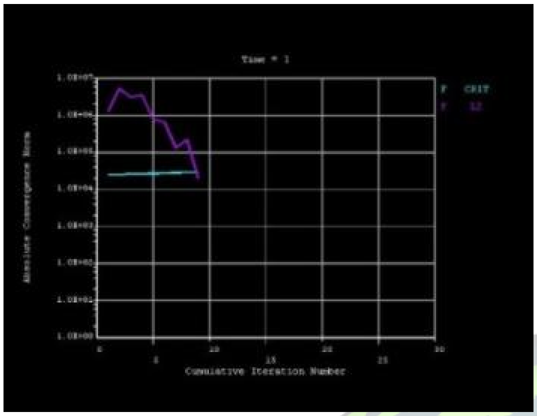

Figure 4: Non-linear convergence graph

In the present study, FEA software ANSYS 13.0 APDL has been used to determine the maximum allowable contact stress in plastics spur gears. Fine meshing as shown in figure 2, has been done in order to get accurate results. A moment of 7599 N-m is applied in clockwise direction on the inner rim of the upper gear.

VI. RESULTS AND DISCUSSIONS

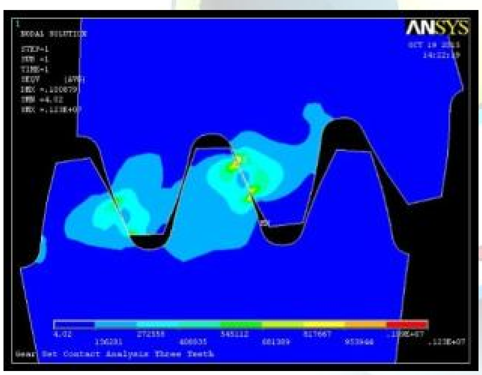

Figure 5: Stress distribution

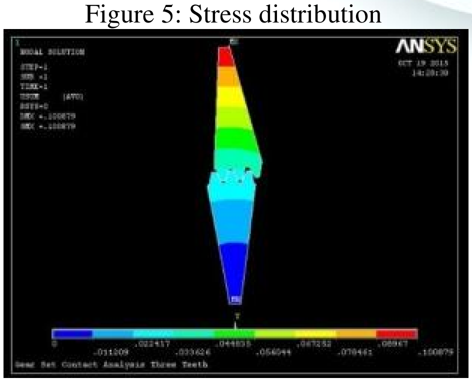

Figure 6: Deformation pattern

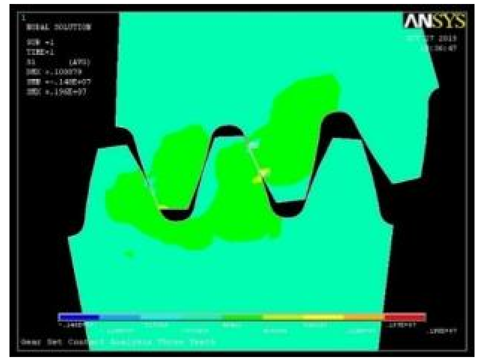

Figure 7: Principle stress

As is clearly indicated in figure 5, the maximum allowable contact stress for plastic spur gears of dimensions given in table 2 and for transmitted torque of 28.94 N-m is 1.24MPa, as determined by FEA using ANSYS APDL 13.0.

Path Distance Vs Von Mises Stress:

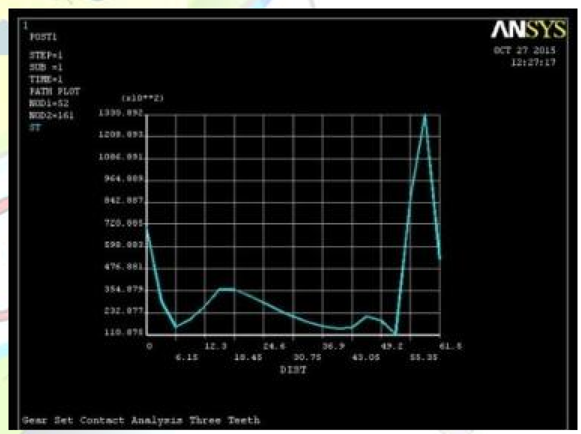

Figure 8: Path Distance Vs Von Mises Stress Graph

Results obtained from Ansys:

From the static analysis using Ansys the deflections and von-mise stress values for Poly-ether-ether-ketone (PEEK) material are obtained as following below tables.

Table 3: Stress at different RPM at pressure angle 20

S. No	Results	Speed 500rpm	Speed 750rpm	Speed 1000rpm	Speed 1250rpm
1	Pressure (N/m^2)	11398.63	7599.08	5699.31	4559.45
2	Contact Stress (MPa)	1.84	1.23	0.92	0.73

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3	Deflections (mm)	0.144	0.10	0.075	0.060

Graph 1: Speed v/s Stress

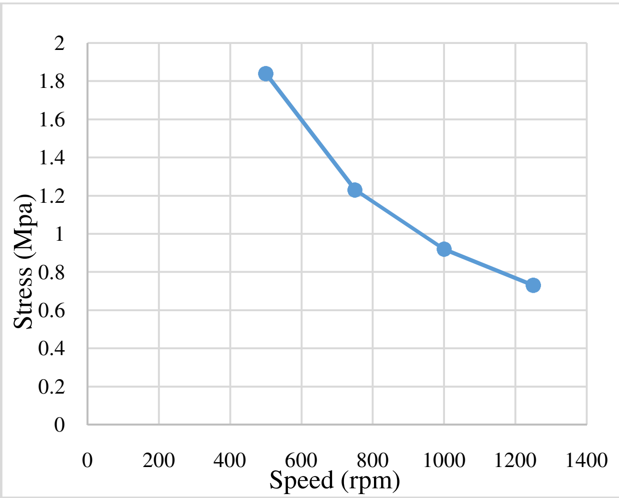

Figure 9:Speed v/s Stress graph

Graph 2: Speed v/s Deflection

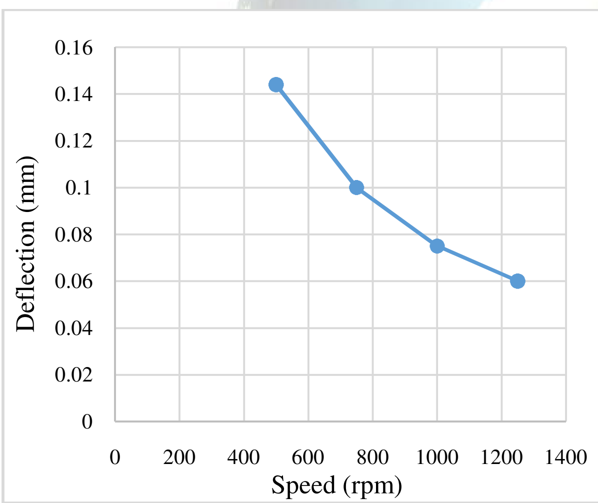

Figure 10:Speed v/s Deflection

CONCLUSION

The finite element analysis of spur gear is done to determine the maximum contact stress by ANSYS 13.0. Contact stress for peek material at different speed conditions are obtained in this study.

The parametric model is capable of creating spur gears with different modules and number of teeth by modifying the parameters and regenerating the model. Sets of gears having the same module and pressure angle can be created and assembled together. It is possible to carry out finite element analysis such as contact stress between gear teeth pair. In this paper, a 3D deformable-body (model) of spur gear is developed and Contact stress of Peek Material gear was analysed. The speed has increased at certain range and the contact stress was decreased. It was concluded that the plastic gear can be used for heavy duty applications.

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