OPTIMIZATION OF PLASTIC GEARS BY USING ASYMMETRIC TOOTH PROFILE

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Abstract- A gear is basically a toothed wheel that works in tandem with another gear to transmit power or motion to change speed or direction of motion. Gear with asymmetric tooth profile are mainly considered for special applications where the loading of the gear is uni-directional, so the workload on one side is higher compare to other side. The design of asymmetric tooth shape reflects this functionality.

In this paper spur gear of a sugarcane juice machine has modeled with asymmetric tooth profile for different pressure angles on drive side and in order to reduce noise, vibration and low requirement of maintenance metallic gears are replaced with non metallic materials. Gear tooth profile are modeled in Pro-E software and static analysis is conducted by using FEM software. Results obtained are compared with symmetric tooth profile gear. Analytical method is used to calculate bending stress by using Lewis equation for asymmetric tooth gears and values obtained are compared with simulated results.

Index Terms - asymmetric tooth; pressure angle; non-metallic materials.

I. INTRODUCTION TO GEARS

A gear is a rotating machine part having cut teeth, or cogs, which mesh with another toothed part in order to transmit torque. Two or more gears working in tandem are called a transmission and can produce a mechanical advantage through a gear ratio and thus may be considered a simple machine. Geared devices can change the speed, magnitude, and direction of a power source. The most common situation is for a gear to mesh with another gear, however a gear can also mesh a non-rotating toothed part, called a rack, thereby producing translation instead of rotation.

A. Asymmetrical Gears:

Historically, gear geometry improvement efforts were concentrated on the working involute flanks. They are nominally well described and classified by different standard accuracy grades, depending on gear application and defining their tolerance limits for such parameters as run out, profile, lead, pitch variation and others. Working involute flanks are also modified to localize a bearing contact and provide required performance at different tolerance combinations and possible misalignment as a result of operating conditions (temperature, loads, etc.). Their accuracy is thoroughly controlled by gear inspection machines. The gear tooth fillet is an area of maximum bending stress concentration. An overall weight reduction may be realized by using gears with higher capability than conventional gears in the primary drive direction, even if some capacity is sacrificed in the secondary coast direction.

The design intent of asymmetric gear teeth is to improve performance of the primary drive profiles at the expense of the performance for the opposite coast profiles. In many cases the coast profiles are more lightly loaded, and are loaded only for a relatively short duration. Asymmetric tooth profiles make it possible to simultaneously increase the contact ratio and operating pressure angle in the primary drive direction beyond the conventional gears' limits. The main advantage of asymmetric gears is contact stress reduction on the drive flanks, resulting in reduced gear weight and higher torque density.

Fig.1. Teeth alignment in Spur gears

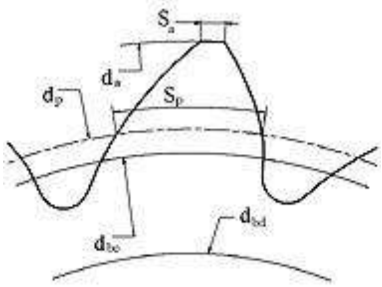


Fig.2. Asymmetric Gear Teeth

B. Benefits of asymmetrical gears:

The design intent of asymmetric gear teeth is to improve the performance of the primary contacting profile by degrading the performance of the opposite profile. The opposite profile is typically unloaded or lightly loaded during relatively short work period. The "improved performance" of the primary profile provides: Direct Gear Design of the asymmetric gears independently defines the drive tooth profile for maximum load capacity, the cost tooth profile, and the fillet for sufficient flexibility. It provides high gear transmission performance

- with low noise and vibration.

- Increased load capacity
- Reduced Weight & Size
- Reduced Noise
- Reduced Vibration

C. Selection Of Materials:

The materials that are used for manufacturing of gears mainly depend upon strength and service conditions like wear and noise etc. cast iron material is widely used for manufacture of gears due to its good wearing properties, excellent machine ability and ease of producing complicated shapes by casting method. Plastic materials like Nylon and Polycarbonate etc are used for manufacture of gear, for their certain properties like reduction of weight and noise, high strength, high temperature resistance.

TABLE1: Material properties of cast iron, nylon & Polycarbonate

Material property	Cast iron	Nylon	Polycarbonate
Young's modulus (N/mm^2)	$1.65e^5$	$2.1e^5$	$2.75e^5$
Poisson s ration	0.25	0.39	0.38
Density (kg/mm^3)	$7.2e^{-6}$	$1.13e^{-6}$	$1.1e^{-6}$
Ultimate tensile strength (Mpa)	320-350	55-83	55-70

II. **CHOICE OF PRESSURE ANGLES AND MODULES:**

Pressure angles of 20, 25°, 30° and 35° are used in plastic gears. The 20° pressure angle is usually preferred due to its stronger tooth shape and reduced undercutting compared to the 14.5° pressure angle system. The 25° pressure angle has the highest load-carrying ability, but is more sensitive to centre distance variation and hence runs less quietly. The choice is dependent on the application. The determination of the appropriate module or diametric pitch is a compromise between a number of different design requirements. A larger pitch is associated with larger and stronger teeth.

III. SPECIFICATION OF THE PROBLEM:

In this project work to reduce stresses , weight and noise metallic gear of sugar cane juice machine is replaced with non metallic material. for this we consider two different types of plastic material namely Nylon and Polycarbonate. based on analysis, the best plastic material is recommended for the purpose. also the symmetric tooth profile gears are replaced with asymmetric tooth profile gear for best results. modelling of spur gear is done in Pro E and static analysis is conducted in ANSYS. after analysis the stresses and deflection of existing material is compared with plastic materials that are considered and best is considered.

IV. THEORETICAL CALCULATIONS OF CONVENTIONAL CAST IRON SPUR GEAR:

In the present analysis the maximum torque, allowable stress and tangential load of the spur gear are calculated based on the desired sugarcane juice machine motor specifications and are as following below:

Specifications of sugarcane juice machine motor: Power (P) = 1.5 kW = 1500watt Speed (N) = 1400 RPM

Power (P)= $(2*\pi*N*T)/60$ KW

$1500 = (2*\pi*1400*T)/60$ KW

Torque (T) = $(1500*60)/(2*\pi*1400)$ KW

T = 10.2313 N - m

T = 10231.38 N - mm

T = F*(d/2)

F = T/((d/2))

F = 10231/90

F = 113.677 N

Where F is the tangential load

Using Lewis equation

$\sigma_b = F/(b*m*y)$ N/mm^2

$= 113.677/(54*10*0.35)$

$\sigma_b = 0.6014$ N/mm^2

Where σ_b = the allowable stress

y = the Lewis form factor for asymmetric tooth profile for a combination of pressure angle 20-25

b=the face width of the gear

The Maximum allowable stress as per the design of the desired spur gear, $\sigma_b = 0.6014$ N/mm^2

V. PARAMETRIC MODELING OF AN ASYMMETRIC INVOLUTE GEAR:

Asymmetric gear is model in proe software by using parametric approach. The parameters required to model the gear are show in table

TABLE2 : Parameters of the Asymmetric Gear

Parameters	Symmetric toothed gear	Asymmetric toothed gear
Number of tooth (N)	18	18
Diametral pitch (P)	0.1	0.1
Drive pressure angle (ϕd)	20	20,25,30,35
Coast pressure angle (ϕc)	20	20

To generate asymmetric profile consider Number of teeth(N), Diametral pitch (P) and pressure angle as input parameters and other parameters have been calculated from equations of gear design mentioned below.

Pitch_Circle_Diameter = Number_of_Teeth /Diametral_Pitch
Addendum = 1/Diametral_Pitch
Dedendum = 1.157/ Diametral_Pitch
Addendum_Circle_Dia = Pitch_Circle_Diameter + 2* Addendum
Duodenum_Circle_Dia = Pitch_Circle_Diameter – 2* Duodenum
Drive_Base_Circle_Dia = Pitch_Circle_Diameter * Cos(Drive_Pressure_Angle)
Coast_Base_Circle_Dia = Pitch_Circle_Diameter * Cos(Coast_Pressure_Angle)
Fillet_radius = 0.4 * Addendum
Face_Width = 0.0625*Pitch_Circle_Diameter.

and these equations are entered in Pro E editor which has been shown in figure below

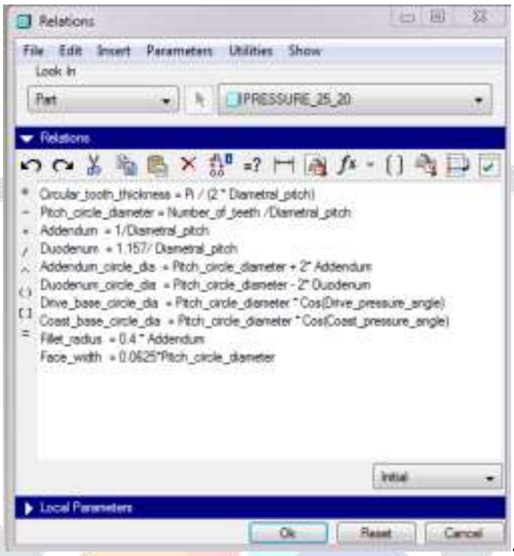


Fig.3. Gear design equations have been mentioned in Pro-E

with reference to Frederick W. Brown et al [11] we create an asymmetric curve by using datum curve generation tool with curve equation in cylindrical co ordinate system as shown below.

For Drive direction
todeg=180/pi
alpha=t*sqrt((Da/Dbd)^2-1)
alpha2=sqrt((Dp/Dbd)^2-1)
r=0.5*Dbd*sqrt(1+alpha^2)
theta=alpha*todeg-atan(alpha)-(alpha2*todeg-atan(alpha2))-(90/n)-1
z=0
For Coast direction
todeg=180/pi
alpha= t*sqrt((Da/Dbc)^2-1)
alpha2=sqrt((Dp/Dbc)^2-1)
r=0.5*Dbc*sqrt(1+alpha^2)
theta=alpha*todeg-atan(alpha)-(alpha2*todeg-atan(alpha2))-(90/n)+.4
z=0

by using above equations we generate a single tooth gear with different pressure angles for drive side. we considered the following combinations of pressure angles

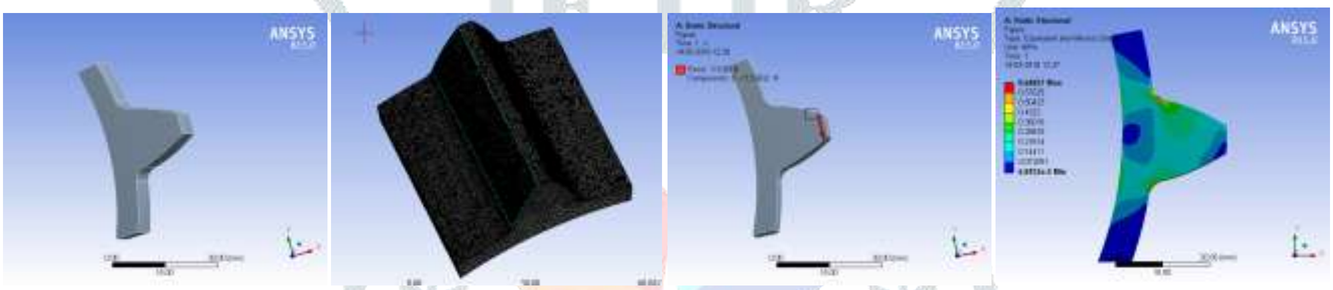
TABLE3 : 3D Models of Asymmetric Tooth Profiles

3d model of asymmetric tooth gear	**Coast and drive side pressure angles**
	20-35

	20-30
	20-25
	20-20

VI. STATIC ANALYSIS BY USING ANSYS

Initially static analysis is conducted on 20-25 profile gear by considering it as cantilever beam with one end is fixed and a load of 113.677 N is applied on tooth. the obtained results are compared with theoretical values calculated by using Lewis theorem for asymmetric tooth profile gears [12].



(a) (b) (c) (d)

Fig.4. a) model of asymmetric toothed gear with 20-25 pressure angle profile b) meshed gear teeth d) stress distribution in 20-25 profile gear.

Using Lewis equation [12]

$\sigma_b = F/(b*m*y)$ N/mm^2

$= 113.677/(54*10*0.35)$

$\sigma_b = 0.6014$ N/mm^2

Where σ_b = the allowable stress

y = the Lewis form factor

b=the face width of the gear

Further we perform the static analysis for different pressure angles and for different materials of gears, at a pressure of 1Mpa. Boundary conditions that are considered are as shown below.

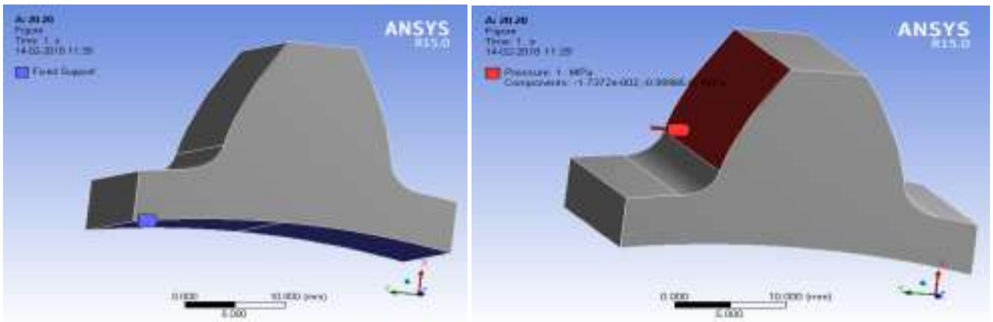
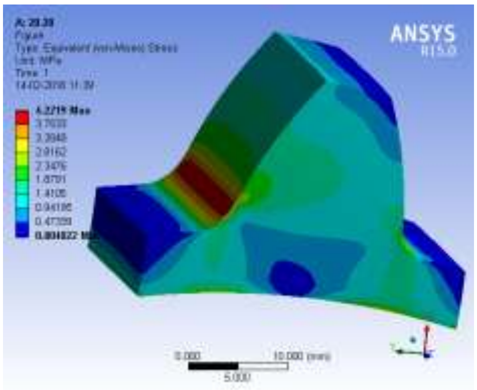


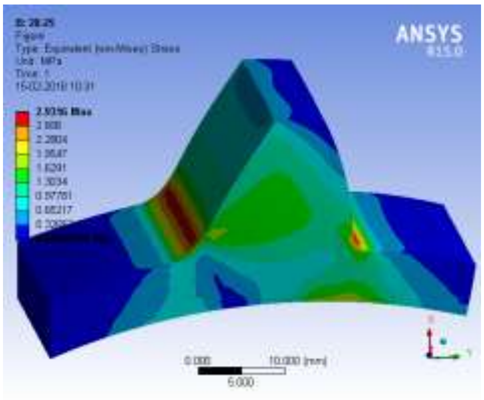
Fig.5. a) fixed support at the base of teeth b) pressure applied at face of teeth

VII. RESULSTS AND DISCUSSIONS

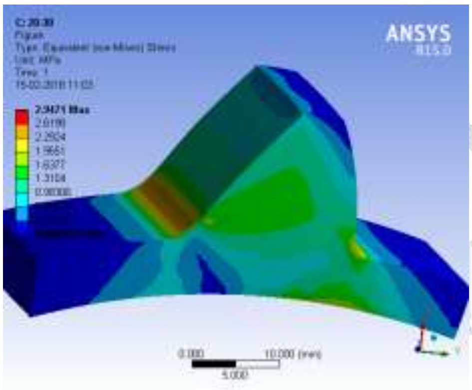
The simulation results of asymmetric teeth profile gears for different pressure angles are shown below



(a)



(b).



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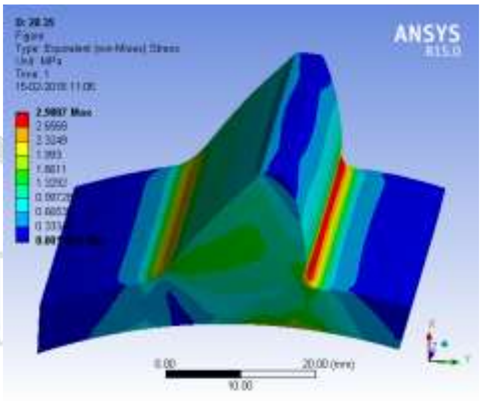
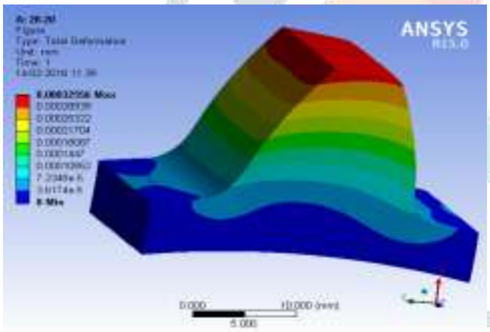
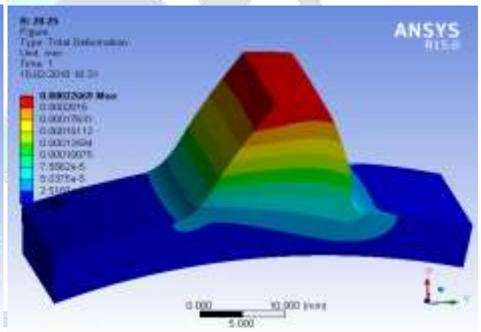


(d)

Fig.6. a) Stress distribution in nylon material gear for 20-20 pressure angle profile b) stress distribution in 20-25 profile gear c) stress distribution in 20-30 profile gear d) stress distribution in 20-35 profile gear



(a)



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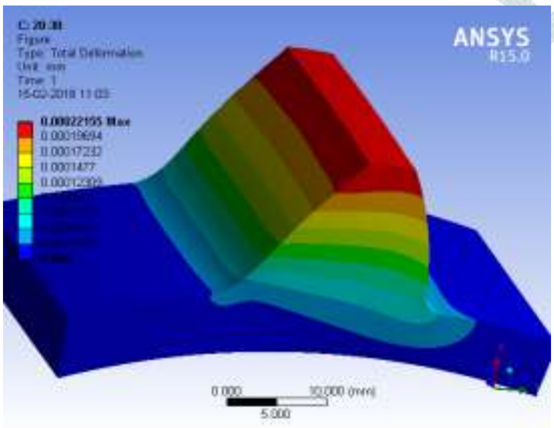
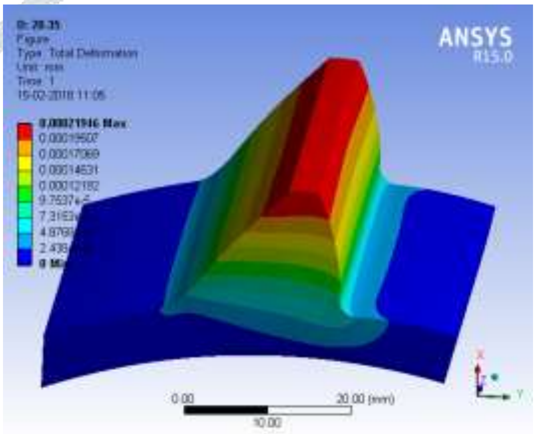


(c)



(d)

Fig.7. a) Displacement pattern in nylon material gear for 20-20 pressure angle profile b) Displacement pattern in 20-25 profile gear c) Displacement pattern in 20-30 profile gear d) Displacement pattern in 20-35 profile gear

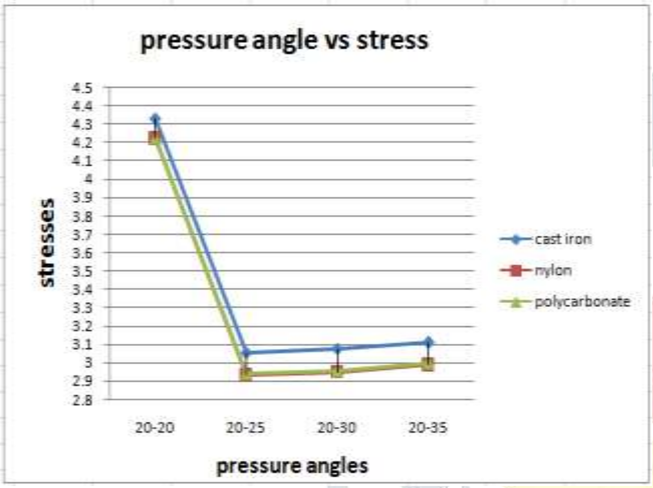
The stresses and deformation of gears for materials cast iron, nylon and polycarbonate are shown in below table.

TABLE4 : Stresses and deformation values for different materials at different pressure angles.

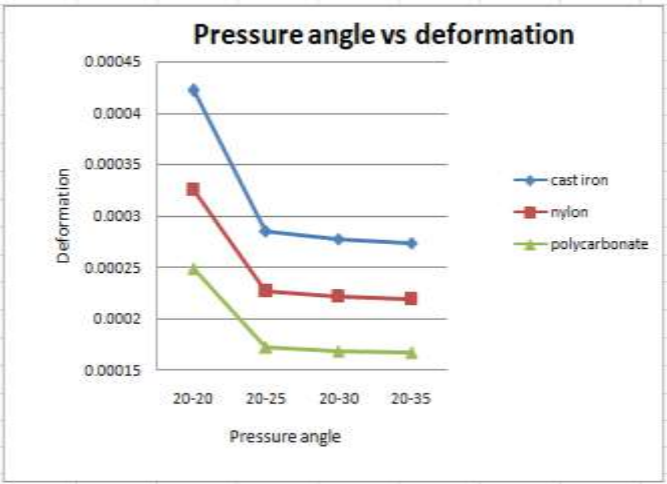
Pressure angles	Materials	Equivalent Stress	Total deformation
20-20 angles	castiron	4.3329	0.00042189
	nylon	4.2219	0.00032556
	Poly carbonate	4.2267	0.00024918
20-25 angles	castiron	3.0557	0.00028565
	nylon	2.9316	0.00022669
	Poly carbonate	2.9412	0.00017309
20-30 angles	castiron	3.0754	0.00027739
	nylon	2.9471	0.00022155
	Poly carbonate	2.9578	0.00016909
20-35 angles	castiron	3.1076	0.00027342
	nylon	2.9887	0.00021946
	Poly carbonate	2.9994	0.00016742

From the above table we can observe that stresses and deformation values obtained for nylon are minimum compare to other two material and also for combination of 20-25 coast and drive side pressure angle is best angles to minimize vonmises stresses in gears.

The graphical representation of stresses and deformations for different material and for different pressure angles are plotted as shown



GRAPH1: Pressure Angle Vs Stress



GRAPH2: Pressure Angle Vs Deformation.

- **CONCLUSION:**

From above analysis we can conclude that metallic gear can be replaced with gear made of nylon material having asymmetric teeth profile with pressure angles 20-25 on coast and drive side.

so we can replace metallic gears with symmetric teeth profile used in sugar cane machine with non metallic gear with asymmetric tooth profile to reduce stresses, weight and noise.

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