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Optimization & Analysis of Forging Press Gear Box

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Abstract:
Gears are the most important component in a power transmission system. Their effectiveness should not decrease with a constant prolonged application and should have well anti wear properties. The assembled gear transmits mechanical energy from a prime mover to an output device. A gearbox can also change the speed, direction, or torque of mechanical energy. Gear box is indicated when the application involves high speeds, large power transmission where noise abatement is important. Thus gear needs to be redesigned, providing energy saving by weight reduction, providing internal damping, reducing lubrication requirements, without increasing cost. This work is to explore the development of composite automotive gear box with optimum design and composite material selection at conceptual design stage for weight reduction to get better fuel efficiency with fulfilling needs of anti-fade characteristics, less power loses due to weight, corrosion resistant design and more consolidated design. The demands of material performances are so great and diverse that no one material is able to satisfy them. Composite material system results in a performance unattainable by the individual constituents. Composite materials offer the advantage of a flexible design that can be tailored to the design requirements. The specific composite materials Glass filled polyamide in particulate form is used for herringbone gears owing to better strength, recyclability, low density and less friction. Glass/epoxy is used for gear housing and shafts for strength requirements, orthotropic properties. Finite element analysis allows entire designs to be constructed, refined, and optimized before the design is manufactured with dynamic effects in low cost.

Key words: *optimization, forging press, gear box, and ansys.*

1. Introduction

Gears have wide variety of applications. They form the most important component in a power transmission system. Advances in engineering technology in recent years have brought demands for gear teeth, which can operate at ever increasing load capacities and speeds. The gears generally fail when tooth stress exceeds the safe limit. Therefore, it is essential to explore the alternate Gear material. The important considerations while selecting a Gears material are the ability of the Gear material to withstand high frictional temperature and less abrasive wear. Weight, manufacturability and cost are also important factors those are need to be considered during the design phase. Moreover, the Gear must have enough thermal storage capacity to prevent distortion or cracking from thermal stress until the heat can be dissipated. It must have well anti fade characteristics i.e. their effectiveness should not decrease with constant, prolonged application and should have well anti wear properties. The quest for energy saving with increased performance of mechanical components has risen significantly over the years has resulted in use of composite material in greater percentage. Weight reduction properties with adequate strength have successfully replaced metallic components with composite material. Moreover, the use of composite materials has increased because of their properties such as high specific stiffness, corrosion free, ability to produce complex shapes, high specific strength and high impact energy absorption etc. Product development has changed from the traditional serial process of design, followed by prototype testing and manufacturing but to more on computer aids. Developments in Computer aided engineering has taken at a rapid pace have realty influenced the chain of processes between the initial design and the final realization of a product. Ability of CAE software's on product designing, 3d visualization, analysis, simulation has impacted a lot on time and cost saving to the industry.
From the literature review Static analysis of herringbone gear with gear box is conducted using composite materials. Composite material used is glass filled polyamide. After static analysis we got the result that overall weight is less than almost 60% while comparing with component made up of conventional material like steel and aluminum. Also in this work, the exploration of composite material gearbox is done to replace the existing metallic gearbox for weight saving and other composite material benefits. In doing so,

computer aided engineering has been found to be very useful and is preferred for various design stages. Reference model of gear box is selected and CATIA is used to develop 3D models of various design concepts. Solid model for herringbone gears are done using parametric approach i.e. whole dimensions of gears are controlled by set of five variable parameters. Glass filled polyamide composite material is used for gears and E- glass/Epoxy for shafts and gear housing. CAD models are analyzed using ANSYS for Equivalent (von-Mises) stress and Equivalent (von-Mises) elastic strain for a Torque of 200N.mm. Comparisons of various stress and strain results with composite and metallic material are also performed and found to be lower for composite material. Composite material gearbox has provided the substantial weight reduction and is designed to carry the same torque as steel gearbox. The composite material gear weighs 678.775 kg prototype while the reference existing model weighs about 1628.44 kg and gives the weight reduction of 60%.

This work is to explore the development of composite automotive gear box with optimum design and composite material selection at conceptual design stage for weight reduction to get better fuel efficiency with fulfilling needs of anti fade characteristics, less power loses due to weight, corrosion resistant design and more consolidated design. Analysis of gear box is carried out so that these can be prevented from failure. When failure occurs, they are expensive not only in terms of the cost of replacement or repair but also the cost associated with the downtime of the system of which they are a part. Reliability is also a critical economic factor and for designer to produce gears with high reliability, its need to be accurately predicting stress experienced by the loaded gear teeth.

2. Experimental Procedure

2.1. Model Generation

- Proper modelling of the parts is very important for getting accurate results of analysis.
- Creating the parts and its dimensioning scheme are important steps.
- The components of the gearbox were modelled in the part design of CATIA.

The gearbox consists of the following parts:

Sl. No.	Pressure angle (A) (degree)	Modulus (m) (degree)	Number of teeth (Z) (integer)	Helix Angle (psi) (degree)	Circular tooth Thickness (E) (mm)
Gear 1	15	10	18	15	100
Gear 2	15	12	17	15	100
Gear 3	15	14	29	15	100
Gear 4	15	10	60	15	100
Gear 5	15	12	52	15	100

Table 1: Components of gear box

Serial No	Components	Quantity
1	Gear 1	1
2	Gear 2	1
3	Gear 3	2
4	Gear 4	1
5	Gear 5	1
6	Shaft	4
7	Gear housing	1

Table 2: Components of assembled system

2.2. Gearbox Design Using CATIA V5 R20

2.2.1. Design of Gear 1

- Start with sketcher interface in Catia, draw a circle with root diameter 163.209mm
- Use PAD option and give 100mm as pad length
- Select one of the circular areas to define a sketch plane and draw a profile of gear tooth using Gear diameter, Base diameter, and Pitch circle diameter, and addendum, dedendum and tooth thickness.
- Select the other circular area to define the second sketch, and project the profile of gear tooth.
- Use rotate option with one duplicate to get a helix angle of 15˚.
- Define a multi-section solid using these two sketches, and use fillets at the base.
- Use circular pattern to complete 18 teeth as given for gear 1
- To get the centre distance of double herringbone gear sketch a circle using base diameter and pad it for half of centre distance(20/2=10mm)
- Now one side of herringbone is ready, we can use MIRROR option and select the circular area of centre distance pad as the mirroring plane.
- Use the HOLE command for creating the space for shaft with the diameter of 75mm.

2.2.2. Design of Gear 2

- To design gear 2 follow the same procedures with appropriate values calculated for all parameters.

2.2.3. Design of Gear 3, 4 & 5

- For gear 3, 4&5 follow the same steps and use POCKET and circular pattern for creating the spokes.

2.2.4 Design of Shaft

- Draw a circle of diameter 75mm
- Make pad for 1000mm using mirrored extent of 500mm on one side.
- Do a sketch of rectangle with length 20 mm and base line 30mm from centre of shaft
- Make pocket using this sketch up to 100 mm
- Use circular pattern and create the drive grip at one end of the designed shaft.

2.2.5. Design of Housing

- Use pad option and extrude this sketch for 900mm using mirrored extent of 450mm
- Make shell definitions to create inside space for placing gear components. Use shell inside thickness of 20mm.
- Define a rib for creating the side lines of housing.
- Profile for rib is drawn perpendicular to one lateral face of housing, as given below
- To create the path of rib use boundary option from wireframe and surface and select the rectangular contour of the base of housing.
- Make the holes for supporting the shafts on both left and right lateral faces with diameter of shaft designed before (75mm)
- Arrange them in proper position using rectangular pattern
- Use drafted pad for leg of the housing and arrange it at each corner
- Right click on the part body and go to properties, change transparency level in graphics

2.2.6. Assembly Gear Box

- In assembly design insert the housing with positioning and fix it as the reference.
- Insert one shaft and place it in an appropriate position using coincidence and surface contact constraints.
- Insert same shaft using Fast multi instantiation and place it in predefined locations of the housing.
- Set gear 1 on shaft 1 using coincidence between axes and offset constraints between circular face of gear and lateral face of shaft.
- Set gear 4 on shaft 2 in a manner to get contact with gear 1.
- Place gear 2 on shaft 2 and keep an offset distance of 20mm between gears 4.
- Position gear 5 on shaft 3 to get contact with gear 2.
- Align gear 3 on shaft 3 with an offset distance of 20mm between gears 5.
- Insert gear 3 using fast multi instantiation and align on shaft 4, with a contact between gears 3 on shaft 3.
- Save this assembled drawing as an IGES file

2.3. Analysis of Gearbox with ANSYS Workbench

- Open ansys workbench and select MODAL Analysis settings.
- In engineering data give specifications for the composite materials which we are using for our analysis.
- Right click on geometry and import the IGES file.
- Click on each imported parts and assign the proper material before meshing.
- Mesh the assembled components with a medium size of meshing.
- Assign fixed support on the legs of gearbox housing.
- In modal (A5) select analysis settings, define number of modes to be extracted.
- In solution insert necessary results, here we used vector deformation.
- Click on solve to get results.
- Come back project window and right click on solution, select export data to Transient structural analysis.
- Here we need to define RPM for different time which we consider in the analysis.
- Give RPM from 50 to 250 on the driving gear.
- In solution select the results for deformation, equivalent stress and equivalent strain.
- Click on solve to get the results.

2.3.1. Images of Gears Using CATIA Rendering Option

GEAR 1

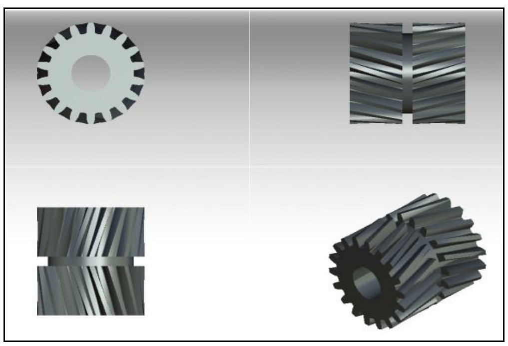

Figure 1: Gear 1

GEAR 2

Figure 2: Gear 2

GEAR 3

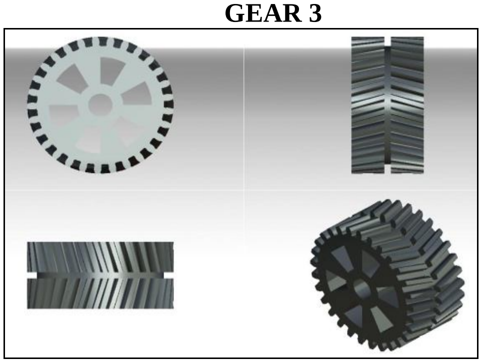

Figure 3: Gear 3

GEAR 4

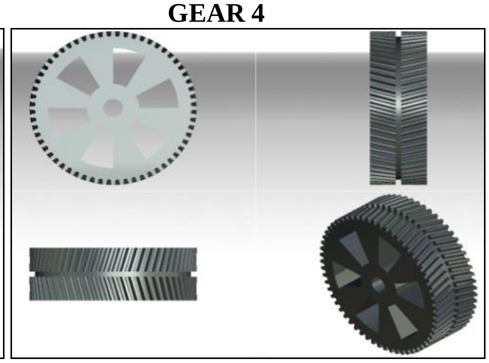

Figure 4: Gear 4

GEAR 5

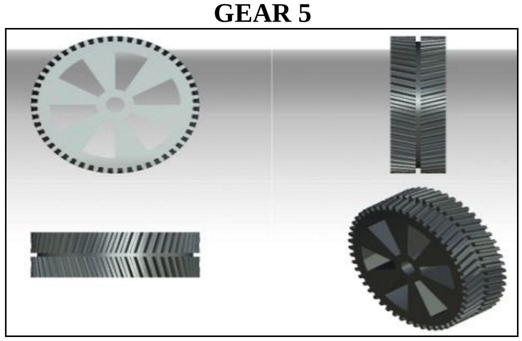

Figure 5: Gear 5

2.4 Assembly of Gears with Invisible Housing

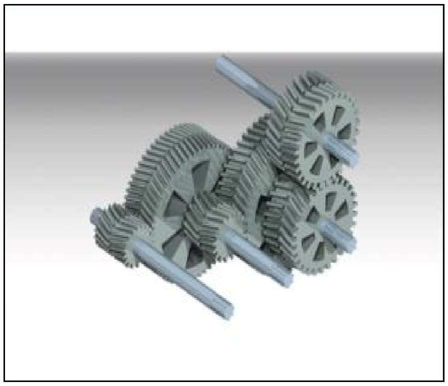

Figure 6: Assembly of gears with invisible housing

2.5. Assembly of Gears with Visible (Transparent) Housing

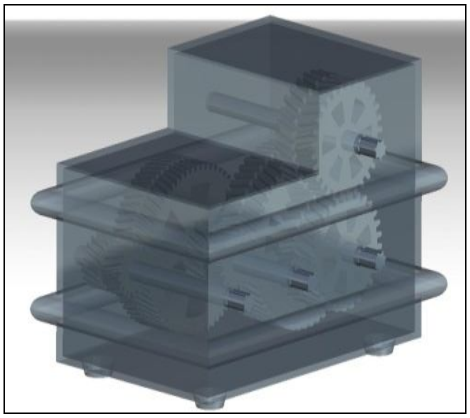

Figure 7: Assembly of gears with visible (transparent) housing

2.5. New Method of Gear Design

New advances in computer technology have made finite element stress analysis a routine tool in design process has given rise to computer-aided design (CAD) using solid-body modelling. Some benefits of CAD are productivity improvement in design, shorter lead times in design, more logical design process & analysis, fewer design errors, greater accuracy in design calculations, standardization of design, more understand ability and improved procedures for engineering changes.

2.6. Role of CAD & Solid Modeling in Gear Design and Analysis

CAD techniques give the design engineer a powerful tool for graphical and analytical tasks. Modern CAD systems are based on ICG in which the computer is employed to create, transform and display geometric data.

CAD helps in:-

- Creating conceptual product models
- Editing, refining the model to improve aesthetics, ergonomics and performance
- Analyze stress, static deflection and dynamic behaviour for different mechanical and thermal loading configurations and carry out quickly any necessary design modifications to rectify deficiencies in the design.

2.7. Assigning Material Properties

After successive modelling using Catia we need to specify the material properties to continue our project to its next phase. The composite material selection for gearbox is done using if –then approach, using production design specification sheet. Glass filled polyamide in particulate form is used for herringbone gears owing to better strength, recyclability, low density and less friction. Eglass/epoxy is used for Gear housing and shafts for strength requirements, orthotropic properties, low cost.

Final material for Composite Gear	
Material Type	Glass filled Polyamide
Material supplier	Dura form
Percentage of glass filling	20 % by volume
Tensile Modulus	5910 MPa
Tensile strength	38.1 MPa
Poisson’s ratio	0.314
Flexural modulus	3300 MPA
Density	840 kg/m3
Moisture absorption	0.30%
Creep resistance	Good
Corrosion resistance	Good
Chemical Resistance	Alkalis, hydrocarbons, fuels & solvents

Table 3: material for Composite Gear

Serial no:	Properties	Value
1	Tensile modulus along X-direction (Ex), MPa	34000
2	Tensile modulus along Y-direction (Ey), MPa	6530
3	Tensile modulus along Z-direction (Ez), MPa	6530
4	Tensile strength of the material, MPa	900
5	Compressive strength of the material, MPa	450
6	Shear modulus along XY-direction (Gxy), Mpa	2433
7	Shear modulus along YZ-direction (Gyz), Mpa	1698
8	Shear modulus along ZX-direction (Gzx), MPa	2433
9	Poisson ratio along XY-direction (NUxy)	0.217
10	Poisson ratio along YZ-direction (NUyz)	0.366
11	Poisson ratio along ZX-direction (NUzx)	0.217
12	Mass density of the material (ρ), kg/mm3	2.6×10^{-6}
13	Flexural modulus of the material, MPa	40000
14	Flexural strength of the material, MPa	1200

Table 4: properties of the composite material

2.8. Finite Element Analysis (FEA)

It is widely accepted method of accessing product performance without the need for physical building and testing. It also shortens prototype development cycle times & facilitates quicker product launch. FEA consists of a computer model of a material or design that is loaded and analyzed for specific results. It is used in new product design, and existing product refinement.

2.9. Optimization of Gears

Optimization of a design is the process by which an objective function is defined with respect to several fixed parameters along with other design variables, and re-evaluated to improve the target value of the function. There are many different ways to optimize and also different range of optimization processes such as one, two or multiple parameter optimization.

Optimization is possible in any aspect of mechanical design if one introduces stringent criteria by which the design must satisfy its functions and can then be developed with respect to what is expected from it. This introduces the concept of “needs analysis”, which summarizes the needs to be met by the design being developed. In the case of the spur gear pair, the “needs analysis” would specify the following conditions:

- The spur gear pair must be strong enough to withstand the applied forces without failing.
- The spur gear pair must be capable of carrying the maximum possible torque for the specific application. In the case of the spur gear pair being modelled in this Thesis, the maximum torque to be face will be 10000Nmm, which will be validated in the following chapter.
- One of the pertinent functions of the spur gear pair with regards to this work has to do with the noise generated due to the vibration generated from the gears meshing. This is summarized by Smith showing that the relationship between noise and TE is one of a linear system5. In order to decrease noise the TE has to be reduced, hence it can be summarized that the TE needs to be minimized for ideal operating conditions. Once the needs of the design have been finalized, it must then be converted into a set of product design specifications. Childs provides an overview of the design process with a mechanical engineering perspective, and reaffirms the points discussed above. The design process involves iterations which depend on the design constraints and criteria, along with the product design specification (PDS).

3. Results and Discussion
Results from ANSYS Workbench

3.1. Gearbox imported in ANSYS

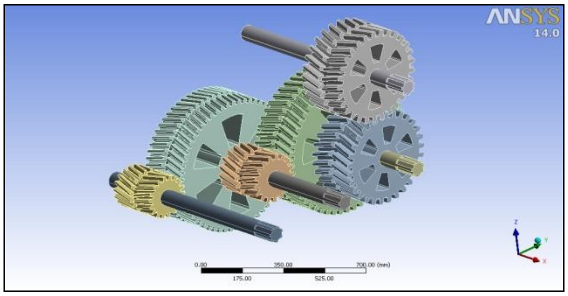

Figure 8: Gearbox imported in ANSYS with invisible housing

3.2. Gear box imported with visible housing

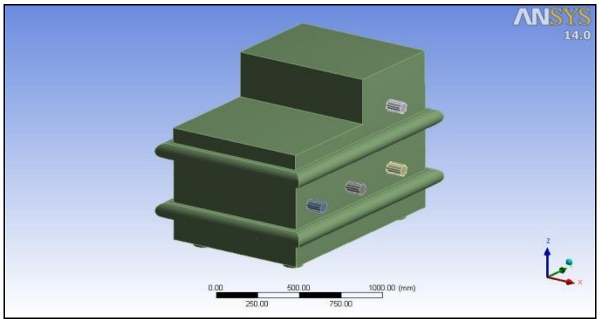

Figure 9: Gearbox imported in ANSYS with visible housing

3.3. Meshing

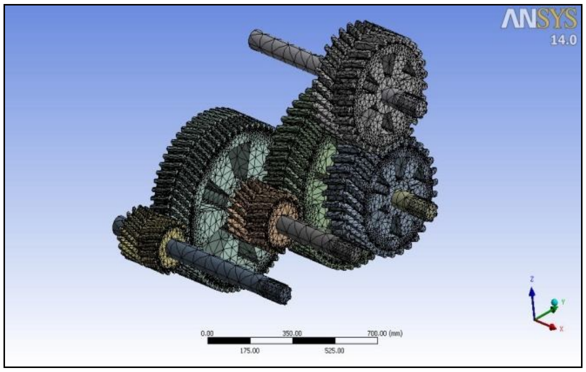

Figure 10: Meshed gearboxes with hidden housing

3.4 Meshed gearbox and housing

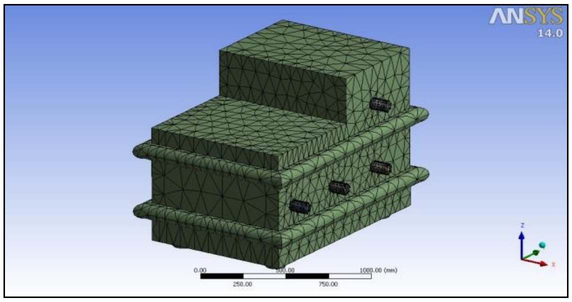

Figure 11: Meshed gearbox with visible housing

Mode	Frequency [Hz]
1.	42.084
2.	55.46
3.	62.473
4.	66.793
5.	76.183
6.	78.973
7.	94.66
8.	95.884
9.	98.425
10.	111.07

Table 5: Results

3.5 Results Obtained from Modal Analysis

While comparing the total deformation with each mode, we can find that, the maximum deformation is in mode 7 with frequency 94.66Hz. The maximum deformation in this mode is 6.4637mm.

3.6. Total Deformation of Gearbox Assembly at Mode 7

- Invisible housing

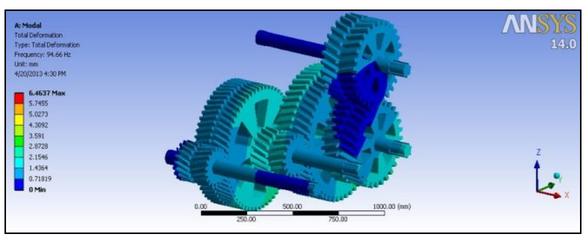

Figure 12: Total deformation with Invisible housing

- With visible housing

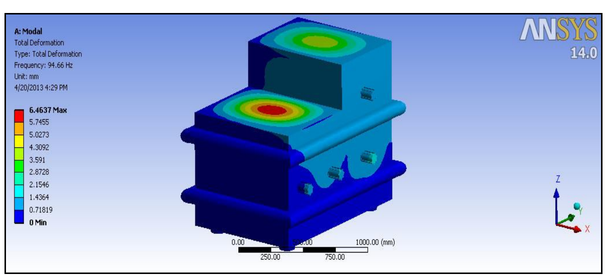

Figure 13: Total deformation with visible housing

- Combination of gear 1-4

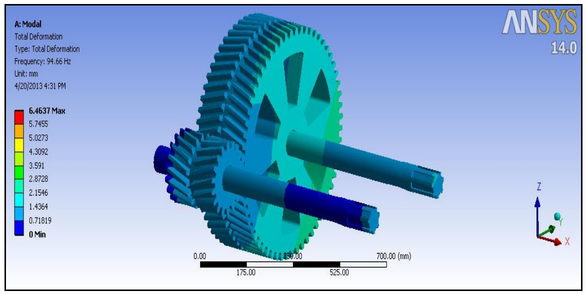

Figure 14: combination of gear 1-4

- Combination of gear 2-5

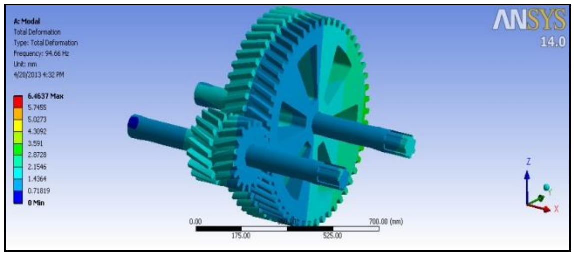

Figure 15: combination of gear 2-5

- Combination of gear 3-3

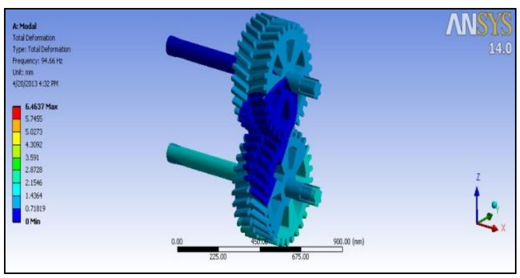

Figure 16: combination of gear 1-4

3.7. Results of Transient Analysis

Load condition applied is given below as tabular data& graph.

Model (A4) > Transient (A5) > Rotational Velocity

Steps	Time [s]	Rotational Velocity [rpm]
1	0.	0.
	1.	25.
2	2.	50.
3	3.	75.
4	4.	100.
5	5.	125.
6	6.	150.
7	7.	175.
8	8.	200.
9	9.	225.
10	10.	250.

Table 6: Results of transient analysis

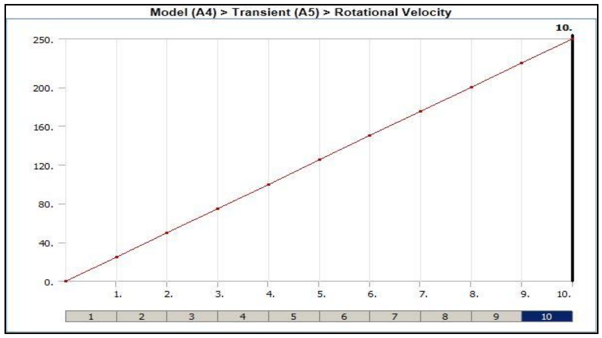

Figure 17: Results of transient analysis

By comparing the values in result table, we can find that maximum deformation occurs at part 6 & part 10. This maximum deformation occurs when the gear box is under the rotational velocity of 250 rpm, which is the maximum we have provided for the analysis.

Model (A4) > Transient (A5) > Solution (A6) > Results			
Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Equivalent Stress*
State	Solved		
Scope			
Scoping Method	Geometry Selection		
Geometry	All Bodies		
Definition			
Type	Total Deformation	Equivalent Elastic Strain	Equivalent (von-Mises) Stress
By	Time		
Display Time	1. s		
Calculate Time History	Yes		
Identifier			
Suppressed	No		
Results			
Minimum	0. mm	2.1986e-015 mm/mm	7.166e-012 MPa
Maximum	4.2105e-007 mm	8.6158e-009 mm/mm	3.0941e-005 MPa
Minimum Occurs On	Part 11	Part 2	
Maximum Occurs On	Part 6		Part 10
Minimum Value Over Time			
Minimum	0. mm	2.1986e-015 mm/mm	7.166e-012 MPa
Maximum	0. mm	2.2288e-013 mm/mm	7.2642e-010 MPa
Maximum Value Over Time			
Minimum	4.2105e-007 mm	8.6158e-009 mm/mm	3.0941e-005 MPa
Maximum	4.2103e-005 mm	8.6146e-007 mm/mm	3.0942e-003 MPa
Information			
Time	1. s		
Load Step	1		
Substep	1		
Iteration Number	11		
Integration Point Results			
Display Option		Averaged	

Figure 18: Transient analysis results

From this table it's clear that the maximum deformation $4.2103x10^{-5}$mm and the equivalent strain $8.6146x10^{-7}$ are negligibly small values.

Time [s]	Minimum [mm]	Maximum [mm]
1.	0.	4.2105e-007
2.		1.6841e-006
3.		3.7893e-006
4.		6.7365e-006
5.		1.0526e-005
6.		1.5157e-005
7.		2.063e-005
8.		2.6946e-005
9.		3.4103e-005
10.		4.2103e-005

Table 7: Table showing the values of total deformation with time

3.8. Total Deformation of Gearbox Assembly at the First Time Step

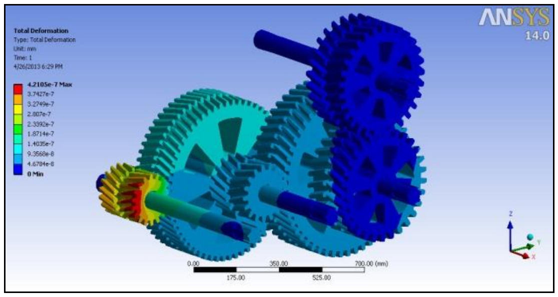

Figure 19: Total deformation of gearbox assembly at the first time step

- Invisible housing

3.9. Total Deformation of Gearbox Assembly at the Middle Time Step

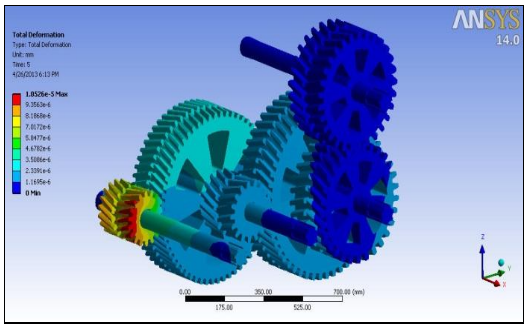

Figure 20: Total deformation of gearbox assembly at the middle time step

- Invisible housing

3.10. Total Deformation of Gearbox Assembly at the Last Time Step

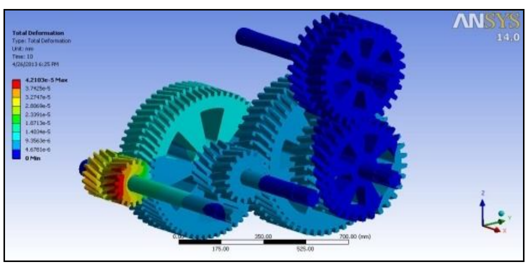

Figure 21: Total deformation of gearbox assembly at the last time step

- Invisible housing

3.11. With Visible Housing

- At first time step

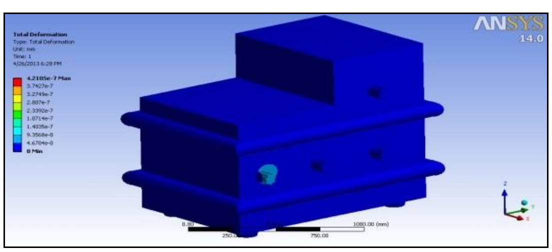

Figure 22: Total deformation of gearbox assembly at the first time step visible housing

- With visible housing at middle time step

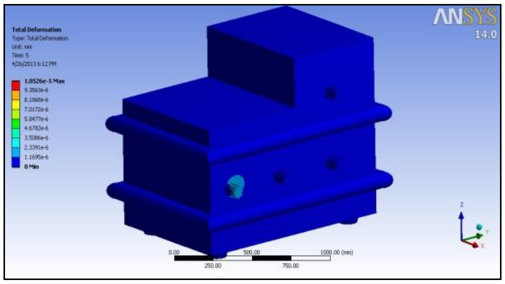

Figure 23: Total deformation of gearbox assembly at middle time step visible housing

- With visible housing at last time step

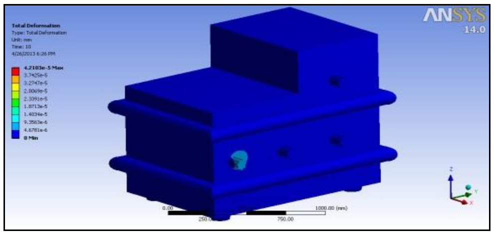

Figure 24: Total deformation of gearbox assembly at the last time step visible housing

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]
1.	2.1986e-015	8.6158e-009
2.	8.876e-015	3.4462e-008
3.	2.0013e-014	7.7537e-008
4.	3.5661e-014	1.3784e-007
5.	5.5685e-014	2.1537e-007
6.	8.0289e-014	3.1013e-007
7.	1.0922e-013	4.2213e-007
8.	1.426e-013	5.5135e-007
9.	1.8054e-013	6.978e-007
10.	2.2288e-013	8.6146e-007

Table 8: for equivalent strain with time

3.12. Equivalent Strain of Gearbox Assembly at First Time Step

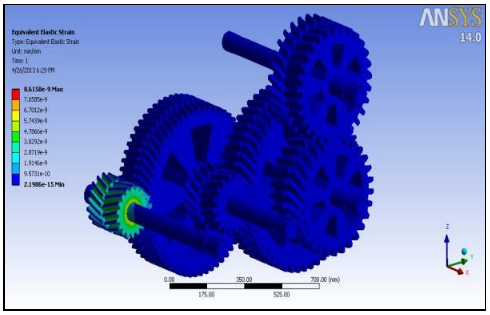

Figure 25: Equivalent strain of gearbox assembly at first time step

- Equivalent strain of gearbox assembly at middle time step

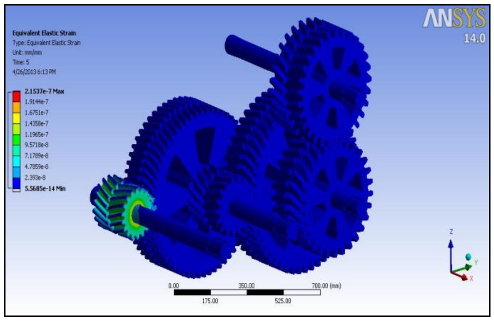

Figure 26: Equivalent strain of gearbox assembly at middle time step

- Equivalent strain of gearbox assembly at last time step

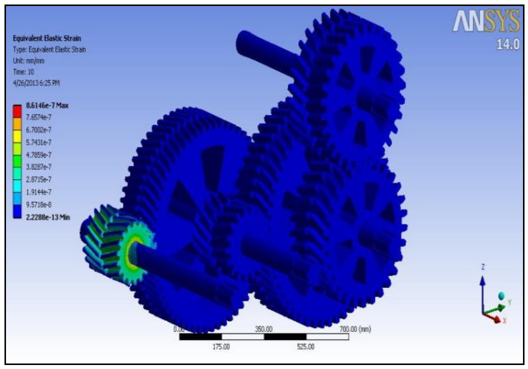

Figure 27: Equivalent strain of gearbox assembly at last time step

Time [s]	Minimum [MPa]	Maximum [MPa]
1.	7.166e-012	3.0941e-005
2.	2.8929e-011	1.2377e-004
3.	6.5226e-011	2.7848e-004
4.	1.1623e-010	4.9508e-004
5.	1.8149e-010	7.7356e-004
6.	2.6169e-010	1.1139e-003
7.	3.5597e-010	1.5162e-003
8.	4.6477e-010	1.9803e-003
9.	5.8843e-010	2.5063e-003
10.	7.2642e-010	3.0942e-003

Table 9: Table for equivalent stress with time

3.13. Equivalent Stress of Gearbox Assembly at First Time Step

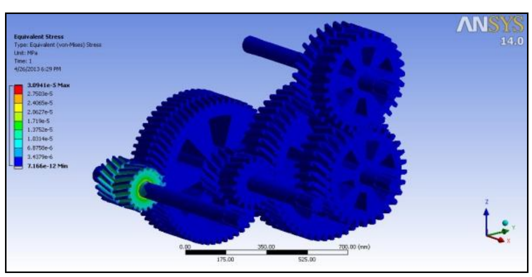

Figure 28: Equivalent stress of gearbox assembly at first time step Equivalent stress of gearbox assembly at middle time step

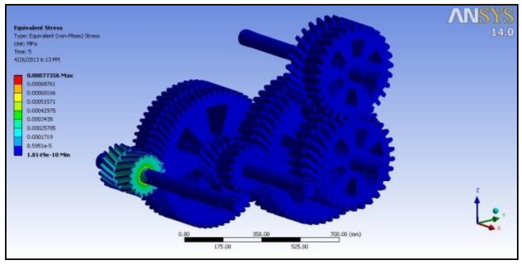

Figure 29: Equivalent stress of gearbox assembly at middle time step

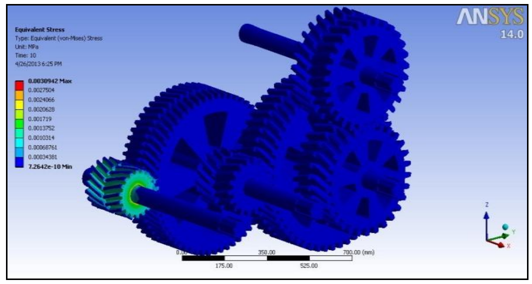

Figure 30: Equivalent stress of gearbox assembly at last time step

4. Conclusion

In this work, the exploration of composite material gearbox is done to replace the existing metallic gearbox for weight saving and other composite material benefits. In doing so, computer aided engineering has been found to be very useful and is preferred for various design stages. Reference model of gear box is selected and CATIA V5 R20 is used to develop 3D models of various design concepts. Solid model for herringbone gears are done using parametric approach i.e. whole dimensions of gears are controlled by set of five variable parameters. Glass filled polyamide composite material is used for gears and E-glass/Epoxy for shafts and gear housing. CAD models are analyzed using ANSYS Workbench 14, for Total deformation for dynamic modal analysis. Then total deformation, equivalent (von-Mises) stress and equivalent (von-Mises) elastic strain for dynamic transient structural analysis for 10 seconds of increasing rotational velocity from 25 to 250 rpm, and got the results for each second. Considering these results we can find that the maximum deformations occurring in each part of our assembly is negligibly small and the assembly is very use full for a forging press process. While comparing the practical results we can find, composite gears have less endurance life. So we can't use these assemblies in a requirement of high speed rotations like automobile engines. According to our analysis, we got satisfactory results for up to 250 rpm, which is more than enough for our requirement of forging press process.

5. References

1. Pankaj Chhabra, Amit Bhatia 'Design & Analysis of Composite Material Gear Box' International Journal of Mechanical Science and Civil Engineering, Volume 1 Issue 1 December 2012 Moscow, Russia.
2. M. Sofian, D. Hazry, K. Saifullah, M. Tasyrif, K.Salleh, I.Ishak 'A study of Vibration Analysis for Gearbox Casing Using Finite Element Analysis' Proceedings of International Conference on Applications and Design in Mechanical Engineering (ICADME) 11 – 13 October 2009, Batu Ferringhi, Penang, MALAYSIA
3. Sandeep V. Thube and Todd R. Bobak 'Dynamic Analysis of a Cycloidal Gearbox Using Finite Element Method' American Gear Manufacturers Association, 1001 N. Fairfax Street, Suite 500 Alexandria, Virginia 22314 October 2012.
4. Vera Nikolic, 'Dynamic model for stress and strain analysis of a spur gear transmission', Journal of Mechanical Engineering July 2009, Vol. 5, Issue 3, Page 233-242, Sophien Str 93 Germany.
5. Denise Carlson -Hiroyuki Yamazaki - Sunao Fukuda - Denso Corp. Christian Leboeuf - H.Peter Kasserra,' Application of Nylon Composite Recycle Technology to Automotive Parts ',SAE paper Paper Number: 2003-01- 0794 DOI: 10.4271/2003-01 0794 November 2003, Detrait, Michigan, USA.
6. Marcia Kurcz ,Burak Baser Harri Dittmar , Joachim Sengbusch and Hans Pfister: 'Replacing Steel with Glass-Mat Thermoplastic Composites in Automotive Spare-Wheel Well Applications', SAE paper, Paper Number: 2005-01-1678DOI: 10.4271/2005-01-1678. December 2005, Detrait, Michigan, USA.
7. Jaroslav Mackerle and Ludvık Prasil ,' Finite element analyses and simulations of gears and gear drives, International Journal for Computer-Aided Engineering and Software, March 2008,Vol. 25 No. 3, pages 196-219, Qingdao, Shandong, China