Static And Modal Analysis of Tractor Power Take Off (PTO) Gearbox Housing

Gopali S Lamani[1], Prof: S.R.Basavaraddi[2],

Assistant Professor, Department of Mechanical Engineering, JSPM NTC RSSOER,India1

Professor, Department of Mechanical Engineering, KLE Dr M.S Sheshgiri CET, Belgaum, Karnataka, India2

***ABSTRACT** : Power Take Off (PTO) is one of the main gearbox of power-train system. It receives power from engine and delivers to other applications of the vehicle. The gearbox housing plays a vital role in gearbox casing. The different components of the PTO are gears, bearings, shafts and oil. A variety of forces (radial and tangential forces)due to gear mesh are acting on gearbox **housing** through the bearing via shaft, hence the design of gear box housing is considered to be very critical.FEA method is used to analyze static properties of the PTO gearbox housing. Modal analysis is a well-established technique which defines the inherent properties of the structure. Modal analysis is used to measure the natural frequency of the system and different mode shape patterns are observed. The analysis is done for two materials Aluminium alloy and Gray Cast Iron using both analytical and theoretical method.*

Keywords: PTO gearbox Housing; Stress Analysis;

1. INTRODUCTION

Gearbox hosing is important component in the power train system. Noise and vibration in the environment or in industry are caused by particular processes where dynamic forces excite the structures.

Most noise and vibration problems are related to resonance phenomena. Resonance occurs when the dynamic forces in a process excite the natural frequencies, or modes of vibration, in the surrounding structures. This is one reason to study the modes and second reason is that they form the basis for a complete dynamic description of a structure.

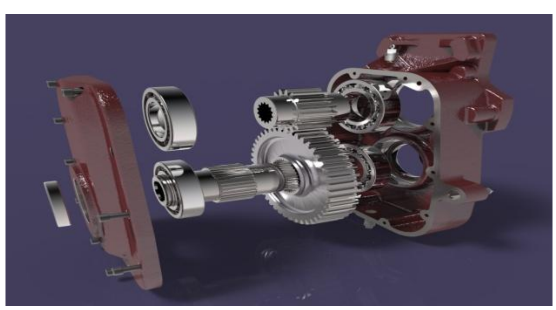


Figure 1: Assembly of PTO Gearbox Housing

Gear noise and vibration is a major problem in many power transmission applications as is evident from the literature[1]. This problem becomes more significant in applications with higher operating speeds where the vibratory excitation, which is related to the gear transmission error, occurs at frequencies in the order of several kilohertz. Most of this vibratory energy generated at the gears is transmitted to the housing and attached structures through the structure-borne paths involving the shafts, bearings, and mounts.

The PTO gearbox housing is an important part in tractor vehicle. The housing encloses different sets of spur gears and bearings to support the shafts. The bottom part is filled with oil. In a power transmission gear system, the vibrations generated at the gear mesh are transmitted to the gearbox housing through the shafts and bearings. To do the analysis of entire gearbox housing it is necessary to do the analysis of casing, force analysis of pinion and gear.

1.1 POWER TAKE OFF

Power Take-Off or **power takeoff** (**PTO**) is any of several methods for taking power from a power source, such as a running engine, and transmitting it to an application such as an attached implement or separate machines. The figure 2 shows the rear view of tractor with PTO gearbox and pump body.

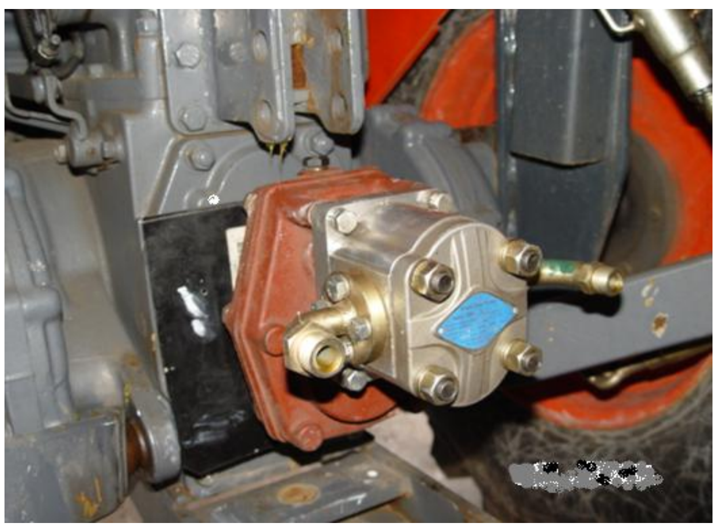


Fig 2: rear view of tractor with PTO gearbox

1.2. POWER TAKE OFF GEARBOX

Power take off gearbox consist of shaft, pinion, spur gear, ball bearings, gearbox housing, Bolts and nuts shown in Fig 3.

- **Shaft: A long cylindrical device such as a rod on a wheel, the shaft extends from the center of the wheel along its axis.**

- **Pinion: Gear with a small number of teeth, especially oneengaging with a rack or larger gear.**
- **Spur Gear: A type of gear that has straight, flat-topped teeth set parallel to the shaft. Spur gears are good for transferring motion.**

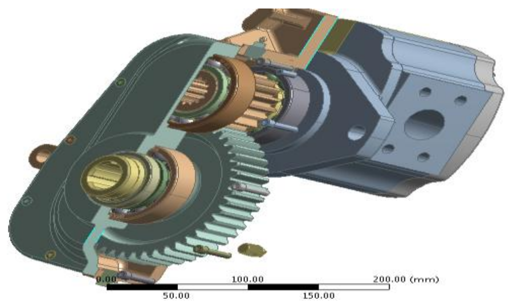


Fig 3: Power Take Off Gear Box

- **Ball Bearing: A rotating support placed between components to increase movement and reduce friction. Ball bearings are a common type of this device.**

- **Gear Box Housing:** The gear housing is the casing that surrounds the mechanical components of a gear box.

2. PROBLEM STATEMENT AND METHODLOGY

2.1. PROBLEM STATEMENT

PTO gearbox of the tractor generates vibrations when engine is running & engaged to separator. The project scope is to understand the generation of the vibration in PTO gearbox and stress induced in the PTO gearbox Housing.

2.2. OBJECTIVE OF PROJECT

- To understand the stress analysis of PTO gearbox housing by using two different properties of material.
- To obtain dynamic characteristics i.e. natural frequencies and mode shapes of the gearbox structure using modal analysis in ANSYS 14.5.

- To generate realistic and representative finite element model of PTO gearbox, which will be then used to evaluate possible deformation pattern (mode shapes) and natural frequencies by comparing two different properties of material.

2.3. METHODOLOGY

The dissertation work will be done in 3 phases as follows:

I. Phase :
   i. Study the literature on Casing, Gear box layout.
   ii. Study the types of Gears, Bearings and its location
II. Phase :
   i. Make 3 D modelling of housing in CATIA v5
   ii. Mesh Generation
   iii. Establish boundary condition.
   iv. Analytical calculation for Gear Forces.
   v. Analytical calculation for Bearing Reaction
III. Phase:
   i. Analysis will be done using ANSYS14.5
   ii. The project divided into Two domains:

- **Modal Analysis:** The natural frequencies of model in free-free conditions are calculated using ANSYS14.5, and by applying the boundary conditions also to compare with theoretical and operating frequencies.
- **Stress Analysis:** The static analysis of the model is performed by applying boundary conditions and forces which are calculated according to the data provided by the company.

3. DESIGN CONSIDERTION AND CALCULATION

3.1. Forces analysis on Gear and Pinion

There are three types of forces generates at gear mesh, they are

- **Radial force**: It is the load that tends to separate the gears. It acts perpendicular to the shaft. This is what is produced by the pressure angle.
- **Axial force**: It is load parallel to the shaft of the gear. It is produced by helical gears because the helix angle, not the pressure angle. It is not produced by spur gears, which have straight teeth that are parallel to the shaft axis.
- **Tangential force**: It is force that acts on moving body in the direction of a tangent to the curved path of the body.

The Spur Gear's transmission force *F*n , which is normal to the tooth surface , as in Figure 4 can be resolved into a tangential component, *F*t , and a radial component, *F*r . Refer to Equation

3.3. Input Parameters of Tractor Power Take Off

Power (P) = 100Hp Rpm (N) = 540

Tangential Force

F_t = 16667.21 N

F_t -Tangential force in newton, T-Torque is in Newton-meter, r_g- Mean radius of gear is in mm.

Radial Force

Where F_r-Radial force

F_r = 6066.36 N

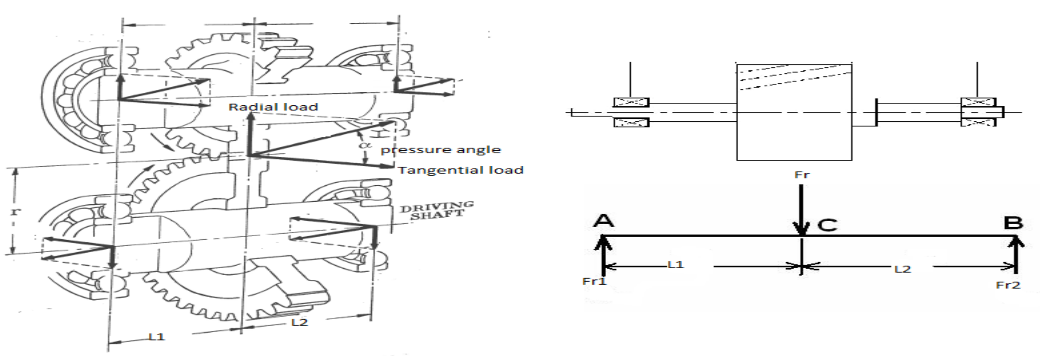


Fig 4 Directions of forces acting on spur gear mesh.

3.4. Calculation of reaction forces at ball bearing

To calculate the reaction forces on bearing due to gear mesh, the problem is simplified to simply supported beam. Figure 4shown schematic representation of various forces and bearing reactions.

3.5 Reaction Forces at Bearing

Radial Reaction forces

$F_{r2} = F_{r1}$ =3033.18 N

Tangential Reaction Forces

$F_{t2} = F_{t1}$ =3033.18 N

Resultant Force acting on Bearing

$$F_1 = \sqrt{{F_{t1}}^2 + {F_{r1}}^2}$$

F_1 = 8868.4 N

Nodes	583261
Element	171362

GEAR MESH FREQUENCY

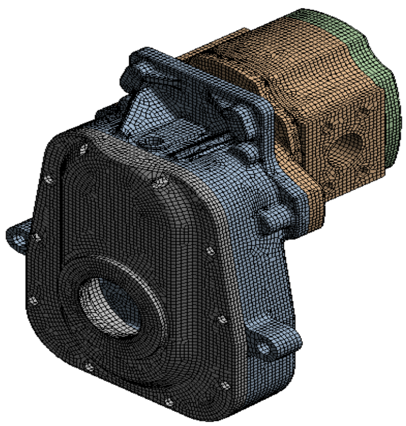
This is the frequency most commonly associated with gears and is equal to the number of teeth on the gear multiplied by the actual running speed of its shaft. A typical gearbox will have multiple gears and therefore multiple gear meshing frequencies. A normal gear mesh signature will have a low-amplitude gear mesh frequency with a series of symmetrical sidebands, spaced at the exact running speed of the shaft, on each side of the mesh components.

Gear mesh frequency $F = k * (N/60)\,Hz$

Where, k= number of teeth on gear N= speed of the rotating shaft (on which gear was mounted)

4. FINITE ELEMENT METHOD

4.1. Meshing: It is one of the basic activities the help in converting the constructed geometry into nodes and elements. It involves discretization of the geometric domain into valid zones for analysis. Fig 5 shows meshing geometry.



Hex Element size	4mm
Element Type	Solid187 Solid186
Contact Type of Element	Canta174 Targe170

Fig 5: Meshed geometry

4.2. Adding Material Property: Mesh definition is followed with associating the appropriate material properties, that covers relevant properties like Young's modulus, density, Poisson's ratio, etc. In this project carried with the two types of materials which are**GCI and Al** and their properties are shown in below table 1

Table.1 Material properties of gray cast iron and Aluminium alloy

Material property	**Gray Cast Iron**	**Aluminium alloy**
Density	7200 kg/m3	2770 kg/m3
Young's modulus	1.1*10^5Mpa	7.1*10^4MPa
Poisson's ratio	0.28	0.33
Yield strength	-	280MPa
Ultimate strength	240Mpa	360MPa

4.3. Assigning Boundary Conditions: In this model there are two forces are generated by the spur gear meshing, which radial force and tangential force. Applied boundary conditions on geometry is as shown in fig 6

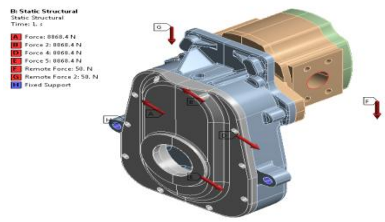


Fig 6 Boundary conditions model

5. RESULT AND DISCUSSION

5.1. STATIC ANALYSIS

Static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads.

5.1.1. Stress

The equivalent von-misses stresses are obtained for Gray cast iron material from the ANSYS. From result it is clear that the maximum stress occurs only at the mid part of two bearing housing and the maximum value is 63.571Mpa as shown fig 6.2 which is less then ultimate strength(240 MPa), hence the design is safe as shown in fig.8

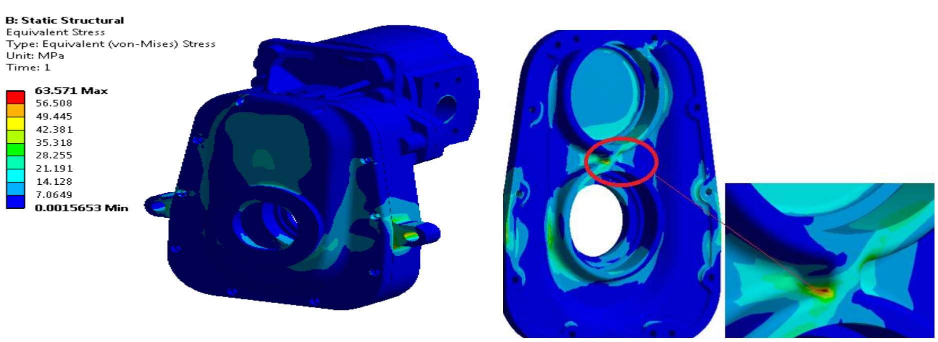


Fig 7: Stress analysis of PTO gearbox Housing model and Maximum stress

5.1.2. Deformation:

The maximum deformation for applied load is 0.0305mm which very small and observed at the portion of upper part of the PTO gearbox as show in fig 9

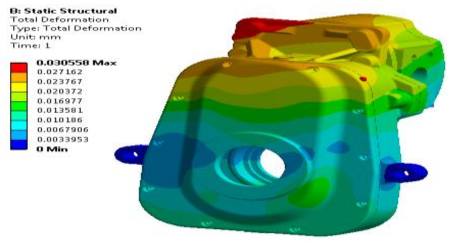


Fig 8:Deformation of PTO gearbox housing

Similarly stress analysis done for Aluminium alloy material

5.2. MODEL ANALYSIS

Modal analysis is a term used to describe any of the processes employed to extract a structure's modal properties (natural frequencies, modal damping factors, and mode shapes) from information about the structure that is presented in a different format.

Modal analysis will help you reduce the noise level emitted by your product.

Modal analysis assists in pointing out the reasons of vibrations because cracking issues of components.

Modal analysis can improve the overall product performance in specific operating conditions.

5.2.1. Free - Free Modal AnalysisGray Cast Iron and Aluminium Alloy

First modal analysis on the assembly is made without applying any boundary conditions. This is done to know whether nodal connectivity is there between the parts. This is ensured by seeing the first six set values, which will be zero. No damping effects included. And seventh mode gives the natural frequency (**948.42 Hz** for gray cast iron and **1230.6 Hz** for Aluminium alloy) of PTO gearbox housing. The following table gives the natural frequencies of the assembly without any boundary condition. And also shown in fig. 8 some modes shapes.

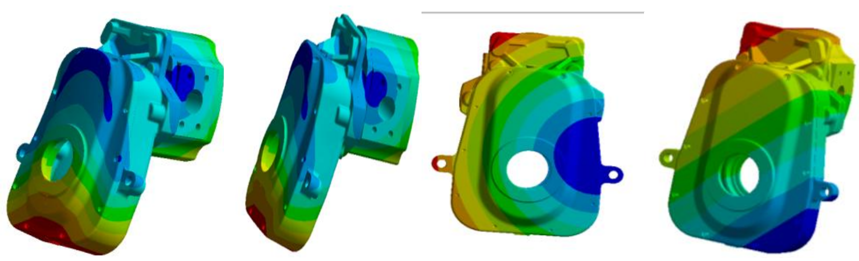


Fig 9: Mode Shapes Pattern

Table 2: free modal analysis of Al and GCI

Modes No	**Aluminium Alloy**	**Gray Cast Iron**
1	0	0
2	0	0
3	**9.51*e-3**	7.173*e-3 Hz
4	1.28*e-3 Hz	1.4139e-2Hz
5	0.3385 Hz	0.14354Hz
6	0.4431 Hz	0.14354Hz
7	**1230.16 Hz**	**948.42**Hz
8	2260.5Hz	1751.Hz

6. CONCLUSION

By reviewing this paper it is clearly understood that the force analysis and forces generated in gearbox housing plays a vital role while designing gearbox housing. so it's very important to understand design of gearbox housing.In this work housing of Power Take Off gearbox is analyzed.

- From stress analysis of Aluminium alloy and Gray cast iron it can be concluded that stress distribution in both materials is almost same i.e. 63.975MPa and 63.575 MPa but there is a slight change in their deformation of the PTO gearbox structure.

- By using the properties of gray cast iron, the natural frequency of housing in ANSYS is found to be 948.42 Hz, under free-free condition and it is compared with gear mesh frequency which is 405 Hz. Thus the gearbox housing is safe from resonance point of view.

- Similarly by using the properties of Aluminium Alloy, the natural frequency of housing in ANSYS is found to be 1230.16 Hz, under free-free condition and it is compared with gear mesh frequency which is 405 Hz.

- By comparing the properties of Aluminium alloy and gray cast iron, it is concluded that Aluminium is having lighter weight than gray cast iron. So it is recommended to use Aluminium alloy in the manufacturing of PTO gearbox housing.

- By comparing the natural frequencies of both the materials, Aluminium Alloy has got higher value of natural frequency than that of gray cast iron. Hence Aluminium alloy is suggested as higher natural frequency is preferred to avoid the condition of resonance.

REFERENCES

1. Vasim Bashir Maner, M. M. Mirza, ShrikantPawar "Design analysis and optimization for foot casing of gearbox" 2014. ISBN: 978-93-84209-15-5

2. Shrenik M. Patil "Analysis Differential Gearbox Casing with Optimization ISSN : 2248-9622, Vol. 3, Issue 6, Nov-Dec 2013, pp.188-193.

3. R. V. Nigade, Prof. T.A.Jadhav and A.M.Bhide. Research and Engineering Kirloskar Pneumatic Co Ltd., Pune, Maharashtra, India "gearbox casing of centrifugal compressor which runs at very high speed" Vol. 1 Issue 4 Dec 2012 ISSN: 2319 – 1058.

4. Snezana ciric-kostic1, svetislavlj. Markovic2 "modal displacement excitation in gear housing walls" Conference IRMES'2002, Jahorina, 2002, p.p. 517-522;