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Design of Tractor Rear Axle Shaft-Function & Analytical Calculations

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1.INTRODUCTION

Off-road vehicle operating conditions vary over wide range. The main source of changes is variety of applications and implements and soil conditions. To match the operating speeds & torques to pull different implements number of ratios provided on off road vehicle are more in number. Also the usage pattern may change drastically as per regional requirement.in addition soil types and moisture content change the traction performance. Agricultural off-road vehicle power requirements & operating conditions vary on large scale. The machine & its components must sustain these changing load conditions; while satisfying all the conflicting requirements. Rear Axle is last component of off-road vehicle power train hence having highest torque also it is the contact point for loads varying in nature, magnitude & direction. Generally off road vehicle offer variety of ratios through multispeed gearboxes to suit different jobs in field and on road in pulling application. To predict the cumulative life of rear axle shaft the fatigue life in each condition is calculated by S-N curve and then cumulative fatigue life is predicted by using miners rule. Effect of geometric stress concentration factor and notch sensitivity is taken into account. Fatigue strength depends upon material, hardness, geometry, surface finish and stress concentration. The mentioned axle shaft has to satisfy geometry requirement and which is heat treated in order to improve performance. The agricultural tractor motor is specialized automobile to suit the various functions at varying conditions involving traction process. It needs to perform the specified functions countering the changing operating conditions limiting its performance, so to study the tractor performance we need to understand the tractor layout and environment of operation.

Operating Conditions

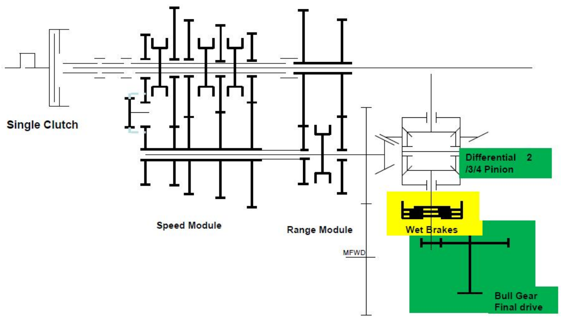
Tractor operating conditions are very special so that the tractor and its operation are studied differently than the other automobiles. Loads coming on the tractor are due to interaction between implement, application, soil, moisture content etc. So these loads vary in various conditions. Also to suit the particular application speed and torque required is different so tractor is provided with large number of ratios through gearbox. Each ratio will give different torque limiting conditions. The agricultural soils, on which the tractor operates, are deformable means they shear when loaded horizontally and compress when loaded vertically. The function of tractor and its implements is to produce such deformable soil with fine grains to provide airy nature beneficial for crops. But such a soil degrades the performance of tractor. The load requirement of the tractor varies on large scale as the application of tractors varies. Tractor is used to pull trolleys and also the implements. Where load depends on draft requirements changing from soil to soil and moisture content and also implement design. [22] The loading conditions on the tractor are variable from job to job and, for efficient operation, ideally require the tractor to be set up to suit each condition. In order to calculate the drawbar power requirements for implements, it is necessary to know the soil resistance or draft force for various implements. This draft force, for implements operated at shallow depths is primarily a function of the width of the implement and the speed at which it is pulled. For tillage tools operated at deeper depths, draft also depends upon soil texture, depth and geometry of the tool. Typical draft requirements of different implements can be calculated using formulae available in standards. The operating conditions for the tractor are highly variable both in time and place, which requires continual monitoring and adjustment of both tractor and implement in operation.

2. FUNCTION

The primary purpose of Axle shaft is to act as power transmitting member from final drive to wheels. This is made possible by taking engine power through final drive component bull gear or planetary carrier according to type of final drive and then giving the same further through spline to axle shaft and to wheel through rim which is mounted on axle flange. Rear Axle is last component of off-road vehicle power train hence having highest torque also it is the contact point for loads varying in nature, magnitude & direction. Generally off road vehicle offer variety of ratios through multispeed gearboxes to suit different jobs in field and on road in pulling application. Rear axle shaft and housing also has to provide sealing to lubrication oil sump; which is done by adding oil seal near flange. Housing bore and axle shaft seal seating ground diameter are located precisely with each other. Rear axle shaft also provide locations for inner and outer bearing for axle. Necessary locating elements like snap rings, circlips and/or locknuts are mounted on rear axle shaft. Main function of transmitting torque from final drive is always done by spline involute or straight mating with female splines of bull gear or planetary carrier.

3.LOCATION

Rear axle shaft is located at the end of transmission and in the same plane of differential in horizontal direction in bull gear or planetary type of final drive. However in some cases of bull gear type final drive axle shaft can be moved up a little to ensure ground clearances. Rear axle centerline decided the wheel base of the vehicle. Following picture shows general architecture of transmission & location of rear axle on one side.



Location of Rear Axle Shaft

Once we finalize the loads as per requirement as discussed. We need to calculate stresses by preparing Shear force and bending moment diagrams as per beam theory.

4.MAIN LOAD COMPONENTS

These are as listed below:

a) Weight on Tire
b) Drawbar Pull
c) Gear Forces

a) Weight

Maximum ballast weight will have some static distribution on front & rear tire. Generally maximum front to rear split will be 25:75, then for rear axle shaft design to be on conservative side the value taken will be 20:80 further more rear reaction on one side will be taken as 0.6 of rear reaction. Means if Total maximum ballasted weight is TMBW reaction considered on rear axle will be 0.8*TMBW*0.6

b) Drawbar Pull

For each tractor layouts; configuration and applications drawbar pull variation is tremendous as discussed earlier. Data acquisition in each application in suitable gear will throw some light on these values. But as per moisture content, sol type and other uncontrollable variations drawbar pull will be varying. The major factors affecting tractor drawbar performance during field operations are tires and ballasting. Tires are usually selected at the time of purchase, while ballasting changes can be made at any time. In practice, ballast weights are not often changed as soil and operational conditions change. To be on safer side drawbar pull can be considered as 65% of weight and half of that can be assumed to be coming on one side.IS 12224 recommends to drawbar pull to be 65% of tractor mass.
Drawbar Pull P = 0.3 X Weight on each axle

c) Gear Forces

On tire mostly used final drive is helical bull gear type which will give three gear forces on axle shaft; these can be calculated for given torque in given gear from gear data. Tangential component will act in vertical plane, separating or radial force will act in horizontal plane and axial load will create moment in horizontal plane this component is negligible as compared to other components. These components can be calculated as below. Torque coming on axle shaft will be calculated from engine limit and traction limit.
P-Drawbar Pull
EP-Engine Power

N-Engine RPM
R-Tire rolling radius
Traction Limit Torque=P X R

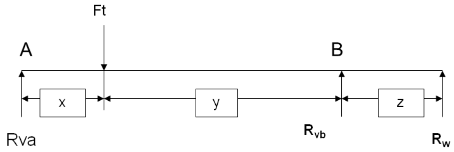
Engine Limit Torque at axle=EP X 60/ (2 x π X N) X Gear Ratio x Gear efficiency X no. of Gear-mesh
T-Axle Torque-Minimum of Traction limit or engine limit
If; PCD-Gear Pitch Circle Diameter
α-Pressure Angle
B-Helix Angle
Ft-Tangential Force
Ft=T/(PCD/2)
Fr- Radial Force
Fr= Ft X Tanα
Fa-Axial force
Fa=Ft X Tanβ

5. Shear Force and Bending moment Diagrams

Once the forces are calculated the shear force and bending moment diagrams are calculated in horizontal & vertical direction. Which are then converted in resultant.Crictical sections for stress concentration is identified and life is calculated in each case. [19]

A] Loading

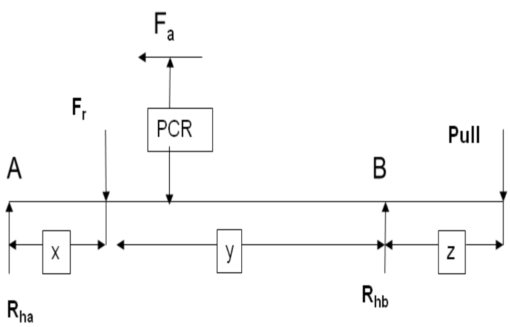
I Vertical Loading of Rear Axle



Vertical Loading

Taking moment about Outer Bearing B
Rva (X+Y) = Ft X Y + Rw X Z
Rva =((Ft x y)+Rw X Z)/(x + y)
Considering equilibrium of forces
Rva + Rvb + Rw = Ft
Rvb = Ft – Rva –Rw

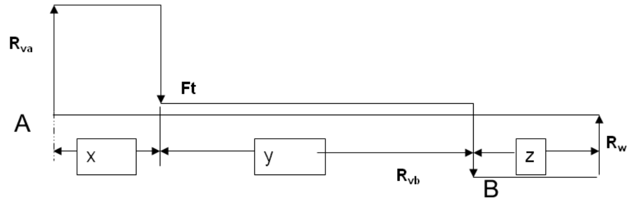
II Horizontal Loading of Rear Axle



Horizontal Loading

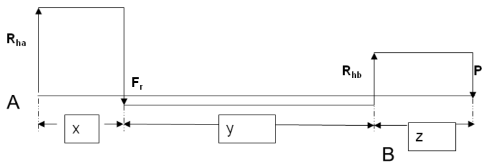
Taking moment about outer bearing B
Rha X (X+Y) + Pull X Z = Fa X PCR + Fr X Y
Rha = (Fa X PCR +Fr X Y – Pull X Z / (X + Y)
Considering equilibrium of forces
Rha =RhB + Fr + P
Rhb + Fr + P –Rha

B Shear Force Diagram I SFD for Vertical Loading



SFD Vertical Loading

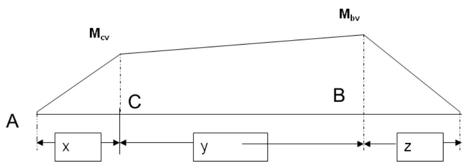
II SFD for Horizontal Loading



SFD Horizontal Loading

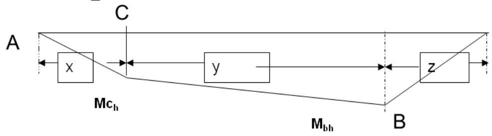
6. BENDING MOMENT DIAGRAM

I Bending Moment for Vertical Loading



Bending Moment Diagram for Vertical Loading Bending, moment at Location C (Mcv) = Rva x X Bending moment at Location B (Mbv) = Rw X Z

II Bending Moment for Horizontal Loading



Bending Moment Diagram for Horizontal Loading
Bending, moment at Location C (Mch) = Rah x X =
Bending moment at Location B (Mbh) = Pull x Z =
Resultant Bending moment at C, Mc (N-m)=√(Mch2+Mcv2) =
Resultant Bending moment at B, Mb (N-m)=√(Mbh2+Mbv2 =
Equivalent Torque, Te, (N-m)= √(Ta2+Mb2
Equivalent Bending moment, Me (N-m)= ½(Mb+√(Ta2+Mb2))
Stresses on the axle shaft at various locations:-
Shear-Stress (Mpa)=Kt*16T*1000/(π*d3)
Bending-Stress (Mpa)=Kb*32M*1000/(π*d3)
Octahedral Stress at outer bearing fillet (Mpa) = √ (Sb2+3*St2)
Equivalent Shear Stress (Mpa)=Kt*16Te*1000/(π*d3)
Equivalent Bending Stress (Mpa)=Kb*32Me*1000/(π*d3)

7.CONCLUSION

Rear Axle shaft function and location in transmission layout discussed.Imperical approach for estimation of load cases possible were established along with inputs causing variation in final usage. Beam theory calculation of shear force and bending moments to determine critical location for stress are determined. Load cases divided into two for ease of calculations like horizontal and vertical loads, which are then finally combined by resultant stress method. These stresses can be further optimized by using finite element methods and geometry modification to improvise stresses. These calculations can be used to start with design by estimation of minimum required diameter.

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