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Design of Differential for Automobile Teaching Aid

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Abstract- Bevel gears areused to transmit the power between two intersectingshafts at almost any angle or speed.In automobiles and other wheeled vehicles, the differential allows each of the driving road wheels to rotate at different speeds, while for most vehicles supplying equal torque to each of them. In this paper, bevel gears in differential of Toyota Hilux 2L 2GD-FTV engineare designed under structural condition when the differential gear ratio is 3.583 at maximum torque400Nm @ 2000 rpm.This 3D model differential is designed by using solidworks software. And then, differential for the teaching aid is fabricated by usingAdditive Manufacturing Technology.

Indexed Terms- Differential, Bevel Gear, SOLIDWORKS, Additive Manufacturing, Teaching Aid

I. INTRODUCTION

A differential is a device, usually, but not necessarily, employing gears, which is connected to the outside world by three shafts, through which it transmits torque and rotation. Expect in some special-purpose differentials, there are no other limitations on the rotational speeds of the shafts. Any of the shafts can be used to input rotation, and the other to output it. Bevel gears transmit power between two intersecting shafts at any angle or between non- intersecting shafts.Pitch cone and back cone elements are perpendicular to each other.In automobiles and other wheeled vehicles, the differential allows each of the driving roadwheels to rotate at different speeds, while for most vehicles supplying equal torque to each of them.[1]

In automobiles and other wheeled vehicles, a differential allows the driving road wheels to rotate at different speeds. This is necessary when the vehicle turns, making the wheel that is travelling around the outside of the turning curve roll farther and faster than the other. The engine is connected to the shaft rotating at angular velocity. The driving wheels are connected to the other two shafts are equal. If the engine is running at a constant speed, the rotational speed of each driving wheel can vary, but the sum or average of the two wheels' speeds cannot change. An increase in the speed of one wheel must be balanced by an equal decrease in the speed of the other.A different automotive application of differentials is in epicyclical gearing. In each differential, one shaft is connected to the engine through a clutch or functionally similar device, another to the driving wheels and the third shaft can be braked so its angular velocity is zero. Several differentials, with different gear ratios, are permanently connected in parallel with each other, but only one of them has one shaft broken so it cannot rotate, so it cannot rotate, so only differential transmits power from the engine to the wheels.[2]

Types of differential are open differential, limited-slip differential, locking differential and automatic locking differential.[3] In this paper, open differential used in Toyota Hilux 2L 2GD- FTV engineis designed and fabricated as teaching aids. This teaching aid model is made of ABS (Acrylonitrile Butadiene Styrene).

Fig. 1. Differentialof Automobile for Teaching Aid

In this paper, 3D modeldifferentialfor teaching aidis designed by using solidworks software and produced by using additive manufacturing technology. The pedagogical model of differential is shown in figure (1).

II. DESIGN OF BEVEL GEARS OF DIFFERENTIAL

In the automobiles, bevel gears are used as the differential crown wheel gear, pinion and side gears. Bevel gears are analogous to a friction cone drive when the conical surface of one drives that of the other cone by friction. Since friction cone drive is not attainable in practice, teeth are provided into these cones for positive drive. The components of differential of automobile are shown in figure (2).

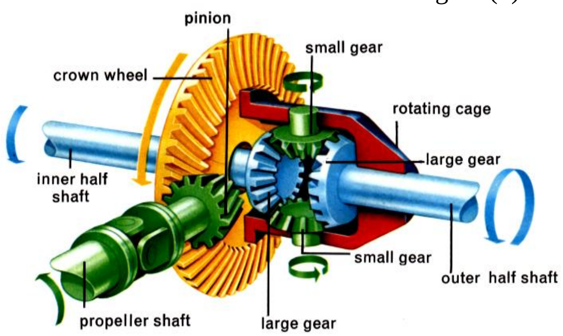

Fig. 2.Components of Differential

The proportions of the bevel gears for crown wheel gear and pinion may be taken as follows:

Addendum, $a = 1 \times m$ (1)

Dedendum, $d = 1.2 \times m$ (2)

Clearance $= 0.2 \times m$ (3)

Working depth $= 2 \times m$ (4)

Thickness of tooth $= 1.5708 \times m$ (5)

Where m is the standard module.

Outside or Addendum cone diameter

$$D_o = D_p + 2a \cos\theta_P \quad (6)$$

Inside or Dedendum cone diameter

$$D_d = D_p - 2d \cos\theta_P \quad (7)$$

Where D_p = Pitch diameter of the pinion (m).

Pitch angle for the pinion

$$\theta_{P1} = \tan^{-1} (T_P / T_G) \quad (8)$$

Pitch angle for the gear

$$\theta_{P2} = 90 - \theta_{P1} \quad (9)$$

A sectional view of two bevel gears in mesh is shown in figure (3). The terms used inconnection with bevel gears are important from the subject point of view.

Various forces acting on the bevel gears, strength of bevel gear, pitch diameter of the gear, pinion, the dynamic load, tangential load and wear load for bevel gearshave been calculated as follows:

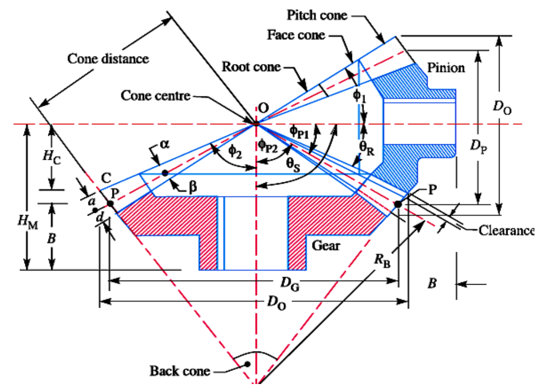

Fig. 3.Terms used in Bevel Gears

A. *Strength of Bevel Gears*

The strength of a bevel gear tooth can be calculated by using the Lewis equation for the tangential tooth load is given as follows:

$$W_T = (\sigma_o \times C_v)\, b\, \pi\, m y' (L-b)/L \quad (10)$$

where σ_o = Allowable static stress and

C_v = Velocity factor

$= 3/(3+v)$, for teeth cut by form cutters,

$= 6/(6+v)$, for teeth generated with precision machines,

v = Peripheral speed in m / s,

b= Face width,

m= Module,

y' = Tooth form factor (or Lewis factor) for the equivalent number ofteeth,

L = Slant height of pitch cone (or cone distance)

$$= \sqrt{\left[\frac{D_G}{2}\right]^2 + \left[\frac{D_P}{2}\right]^2} \quad (11)$$

D_G= Pitch diameter of the gear, and
D_P= Pitch diameter of the pinion.

The dynamic load for bevel gears $W_D$is determined by using the following Buckingham equation,

$$W_D = W_T + \frac{21\, v\, (bC + W_T)}{21\, v + \sqrt{(bC + W_T)}} \quad (12)$$

where W_D = Total dynamic load (N),

W_T = Steady transmitted load (N),

v = Pitch line velocity (m/s),

b = Face width of gears (mm) and

C = A deformation or dynamic factor (N/m).

The static tooth load or endurance strength of the tooth for bevel gearsW_s is given by

$W_s = \sigma_e b\, \pi\,$ my' (L-b)/L(13)

Where σ_e = Flexural endurance limit (MPa).

The maximum or limiting load for wear for bevel gears $W_w$is given by

$W_w = D_p$ b Q K / cos θ_{P1} (14)

Where W_w = Maximum or limiting load for wear (N),

D_p = Pitch circle diameter of the pinion (mm),

Q = Ratio factor,

K = Load stress factor (N/mm^2).

The load stress factor depends upon the maximum fatigue limit of compressive stress, the pressure angle and the modulus of elasticity of the materials of the gears. According to Buckingham,load stress factorK = $\{(\sigma_{es})^2 \sin\varphi / 1.4\}\{(1/E_P) + (1/E_G)\}$ (15)

Where σ_{es} = Surface endurance limit (MPa),

φ = Pressure angle,

E_P = Young's modulus for material of pinion (MPa),

E_G = Young's modulus for material of gear (MPa).

B. Forces Acting on a Bevel Gear

Consider a bevel gear and pinion in mesh. The normal force (W_N) on thetooth is perpendicular to the tooth profile and thus makes an angle equal to the pressure angle (φ) tothe pitch circle. Thus normal force can be resolved into two components, one is the tangential component(W_T) and the other is the radial component (W_R). The tangential component produces the bearing reactions while the radial component produces end thrust in the shafts.[4] Forces acting on the bevel gears are shown in figure (4).

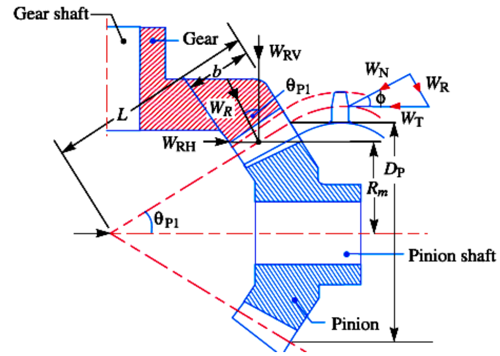

Fig. 4.Forces acting on a Bevel Gear

The magnitude of the tangentialW_T and radial $W_R$components is as follows:

$W_T = W_N\cos\varphi$, and $W_R = W_N\sin\varphi = W_T\tan\varphi$ (16)

Now the radial force (W_R) acting at the mean radius may be further resolved into twocomponents, $W_{RH}$and W_{RV}, in the axial and radial directions. Therefore theaxial force acting on the pinion shaft,

$W_{RH} = W_R\sin\theta_{P1} = W_T\tan\varphi\ \sin\theta_{P1}$ (17)

the radial force acting on the pinion shaft,

$W_{RV} = W_R\cos\theta_{P1} = W_T\tan\varphi\ \cos\theta_{P1}$ (18)

C. Design of a Shaft for Bevel Gears

For design a pinion shaft, $W_T = T/R_m$(19)

Where T is the torque acting on the pinion and R_m is the mean radius of pinion. The bending moment due to W_{RH} and W_{RV} is given by

$M_1 = W_{RV} \times$ overhang distance – $W_{RH} \times R_m$ (20)

And the bending moment due to W_T,

$M_2 = W_T \times$ overhang distance (21)

The resultant bending moment,

$M = \sqrt{[(M_1)]^2 + [M_2]^2}$ (22)

Since the shaft is subjected to twisting moment (T) and resultant bending moment (M), therefore equivalent twisting moment,

$T_e = \sqrt{M^2 + T^2}$ (23)

The diameter of pinion shaft may be obtained by using the torsion equation.

$T_e = (\pi/16) \times \tau \times (d_p)^3$ (24)

Where τ = shear stress for the material of the pinion shaft and d_p = diameter of pinion shaft.[4]

D. Design Calculation of Bevel Gears for Toyota Hilux 2L 2GD-FTV*Engine*

Maximum Torque	400 Nm
Differential Gear Ratio	3.583
Maximum Torque (T)	400Nm @ 2000 rpm
Material Selection of Gears	AISI Alloy 4118
Ultimate Strength	517MPa
Yield Strength ($\sigma_{oP,G}$)	365Mpa
Young's Modulus ($E_{P,G}$)	190 Gpa
Shear Strength (τ)	320 Mpa
Characteristics or Proportions of Bevel Gears	
Teeth of Pinion (T_P)	12
Teeth of Gear (T_G)	43
Pressure Angle (φ)	20°
Pitch Angle for Pinion (θ_{P1})	15.59°
Pitch Angle for Gear (θ_{P2})	74.4°
Standard Module (m)	8 mm
Face Width (b)	60 mm
Addendum (a)	8 mm
Dedendum (d)	10 mm
Clearance	1.6 mm
Working Depth	16 mm
Thickness of Tooth	12.6 mm
Outside or Addendum cone diameter (D_{op})	112 mm
Inside or Dedendum cone diameter (D_d)	77.5 mm
Slant Height (L)	180 mm
Diameter of Pinion (D_p)	96 mm
Diameter of Gear (D_G)	344 mm
Strength of Bevel Gears	
Total Dynamic Load (W_D)	20.7 kN
Flexural Endurance Limit (σ_e)	700 MPa
Endurance Strength (W_S)	56.7 kN
Surface Endurance Llimit (σ_{es})	1050 MPa
Maximum Load for Wear (W_W)	31.5kN
Forces Acting on a Bevel Gear	
Permissible Tangential Tooth Load (W_T)	10 kN
Axial Force Acting on the Pinion Shaft (W_{RH})	978 N
Radiall Force Acting on the Pinion Shaft (W_{RV})	3506 N
Design of a Pinion Shaft for Bevel Gear	
Resultant Bending Moment (M)	1.577×10^6Nmm
Equivalent Twisting Moment (T_e)	1.63×10^6Nmm
Diameter of Pinion Shaft (d_p)	30 mm

III. 3D MODELING OF DIFFERENTIAL

Rapid prototyping in the classroom by students is low-cost ability,but also the fabrication of low-cost high-quality scientificequipment from open hardware designs forming opensource labs. Future applications for 3D printing mightinclude creating open-source scientific equipment.[5] Additive Manufacturing (AM) refers to a process by whichdigital 3D design data is used to build up a component in layersby depositing material.This manufacturing is a new and innovative method used to manufacture solid objects.These 3D shapes are initially created on a computer using solid modeling software, which can be downloaded into the printer. Depending on shape, material, series volume and other criteria, series production is economically possible using metal additive manufacturing.[6]Additive manufacturing system is a process by which digital 3D design data is used to build up a component in layers by deposing material. A range of different metals, plastic and composite materials may be used in additive manufacturing system.[7]

To use additive manufacturing system, firstly, differential of Toyota Hilux 2L 2GD- FTV engineis created by using solidworks software. And then, the model of differential is fabricated by using Maker

Bot machine which is used additive manufacturing system. This Maker Botmachine is shown in figure (5).

Fig. 5.MakerBot Machine

These 3Dprinted gearsare made of ABS (Acrylonitrile Butadiene Styrene)**.**These 3D model gears before printing are shown in figure (5). Finally, these parts of differential areassembled as teaching aid.The assemblyconsists of crown wheel gear, pinion and side gears. This teaching aid for differential was composed in a smaller but similar scale size, including two wheels in order tosimulate the behavior of the differential. This is shown in figure (7).

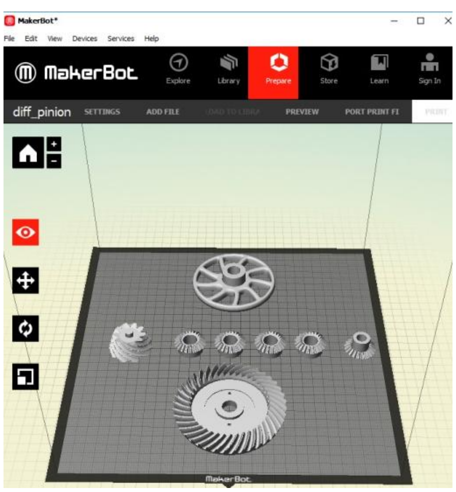

Fig. 6.3D Printed Gears

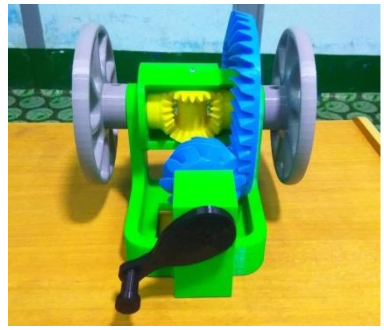

Fig. 7.Differential Assembly

IV. CONCLUSION

Bevel gears in differential of Toyota Hilux 2L 2GD-FTV engineare designed under structural condition when the differential gear ratio is 3.583 at maximum torque 400Nm @ 2000 rpm.Crown wheel gear and pinion of differential are designed with steady transmitted load, static tooth load or endurance strength, limiting load for wear and dynamic load by using AISI Alloy 4118 steel, Yield Strength320 Mpa and Young's Modulus190 Gpa. Crown wheel gear and pinion of differential are designed under structural condition and modeled by using solidworks software. And then, differential for the teaching aid is created by using Additive Manufacturing Technology.Additive manufacturing is opposed to subtractive processes. These 3Dprinted gears are made of ABS (Acrylonitrile Butadiene Styrene)**.**This teaching aid for differential was composed in a smaller but similar scale size, including two wheels in order tosimulate the behavior of the differential. This teaching aid is easy todemonstrate about the function of automobile differential in the classroom.

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