Design & Fabrication of Shaft Driven Bicycle

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Abstract

A shaft driven bicycle is a bicycle that uses a shaft drive instead of a chain which contain two set of bevel gear at both the ends to make a new kind of transmission system for bicycle for getting high reliability system, and more safe system. This project is developed for the users to rotate the back wheel of a two wheeler using propeller shaft. Usually in two wheelers, chain and sprocket method is used to drive the back wheel. Shaft-driven bikes have a large bevel gear where a conventional bike would have its chain ring. This meshes with another bevel gear mounted on the drive shaft. The use of bevel gears allows the axis of the drive torque from the pedals to be turned through 90 degrees. The drive shaft then has another bevel gear near the rear wheel hub which meshes with a bevel gear on the hub where the rear sprocket would be on a conventional bike, and cancelling out the first drive torque change of axis.
Keywords: Bevel gears, Fabrication, Propeller shaft, Reliability, Shaft Driven Bicycle

I. INTRODUCTION

A shaft-driven bicycle is a bicycle that uses a drive shaft instead of a chain to transmit power from the pedals to the wheel arrangement displayed in the following fig 1. Shaft drives were introduced over a century ago, but were mostly supplanted by chain-driven bicycles due to the gear ranges possible with sprockets and derailleur. Recently, due to advancements in internal gear technology, a small number of modern shaft-driven bicycles have been introduced. Shaft-driven bikes have a large bevel gear where a conventional bike would have its chain ring. This meshes with another bevel gear mounted on the drive shaft which is shown in fig I.

Fig. 1: Replacement of chain drive bicycle with driveshaft

The use of bevel gears allows the axis of the drive torque from the pedals to be turned through 90 degrees. The drive shaft then has another bevel gear near the rear wheel hub which meshes with a bevel gear on the hub where the rear sprocket would be on a conventional bike, and cancelling out the first drive torque change of axis.

The design of bevel gear produces less vibration and less noise than conventional straight-cut or spur-cut gear with the straight teeth. The shaft drives only needs periodic lubrications using a grease gun to keep the gears running quite, smooth and efficient transfer of energy from the pedals to the rear wheel. It is attractive in look compared with chain driven bicycle.

Fig. 2: Shaft drive for bicycle

A. *Use of drive shaft:*

The torque that is produced from the pedal and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The drive shaft and differential are used to transfer this torque.

B. *Functions of the Drive Shaft:*

1) First, it must transmit torque from the transmission to the foot pedal.
2) During the operation, it is necessary to transmit maximum low-gear torque developed by the pedal.
3) The drive shafts must also be capable of rotating at the very fast speeds required by the vehicle.
4) The drive shaft must also operate through constantly changing angles between the transmission, the differential and the axles.

II. LITERATURE REVIEW

The first shaft drives for cycles appear to have been invented independently in 1890 in the United States and England. A. Fearnhead, of 354 Caledonian Road, North London developed one in 1890 and received a patent in October 1891. His prototype shaft was enclosed within a tube running along the top of the chainstay; later models were enclosed within the actual chainstay. In the United States, Walter Stillman filed for a patent on a shaft-driven bicycle on Dec. 10, 1890 which was granted on July 21, 1891.

The shaft drive was not well accepted in England, so in 1894 Fearnhead took it to the USA where Colonel Pope of the Columbia firm bought the exclusive American rights. Belatedly, the English makers took it up, with Humber in particular plunging heavily on the deal. Curiously enough, the greatest of all the Victorian cycle engineers, Professor Archibald Sharp, was against shaft drive; in his classic 1896 book "Bicycles and Tricycles", he writes "The Fearnhead Gear.... if bevel-wheels could be accurately and cheaply cut by machinery, it is possible that gears of this description might supplant, to a great extent, the chain-drive gear; but the fact that the teeth of the bevel-wheels cannot be accurately milled is a serious obstacle to their practical success".

In the USA, they had been made by the League Cycle Company as early as 1893. Soon after, the French company Metropole marketed their Acatane.By 1897 Columbia began aggressively to market the *chainless* bicycle it had acquired from the League Cycle Company. *Chainless* bicycles were moderately popular in 1898 and 1899, although sales were still much smaller than regular bicycles, primarily due to the high cost. The bikes were also somewhat less efficient than regular bicycles: there was roughly an 8 percent loss in the gearing, in part due to limited manufacturing technology at the time. The rear wheel was also more difficult to remove to change flats. Many of these deficiencies have been overcome in the past century.

In 1902, The Hill-Climber Bicycle Mfg. Company sold a three-speed shaft-driven bicycle in which the shifting was implemented with three sets of bevel gears. While a small number of *chainless* bicycles were available, for the most part, shaft-driven bicycles disappeared from view for most of the 20th century. There is, however, still a niche market for *chainless* bikes, especially for commuters, and there is a number of manufacturers who offer them either as part of a larger range or as a primary specialization. A notable example is Biomega in Denmark.

Kenneth S. Keyes have performed a patented work or invention related to drive shaft driven bicycle. The object of his invention was to provide a bicycle having a means of linear transmission from the pedal to hub of the bicycle for better efficiency & speed ratios than prior bicycle. A number of problem may be associated with traditional coaster or 3-speed bicycle chains. They are subjected to slippage if the length of the chain is not correctly adjusted.

To overcome above problem, Keyes designed a bicycle which had a driver bevel gear connected to the pedals, a driven bevel gear at the hub of the rear wheel, one or more drive shafts having beveled gears at each end & capable of transmitting the rotation of the driver gear to the driven gear.

Improved bicycle infrastructure is positively and significantly correleted with higher rates of commuting bybicycle that could include promotion of folding bicycle. Most people understand the general concept of a folding bicycle but do not recognize the overall value of improved product design givens that few people are willing to pay for additional costs.

III. COMPONENTS OF BICYCLE

A. *Paddle:*

A bicycle pedal is the part of a bicycle that the rider pushes with their foot to propel the bicycle. It provides the connection between the cyclist's foot or shoe and the crank allowing the leg to turn the bottom bracket spindle and propel the bicycle's wheels. Pedals usually consist of a spindle that threads into the end of the crank and a body, on which the foot rests or is attached, that is free to rotate on bearings with respect to the spindle. Part attached to crank that cyclist rotate to provide the bicycle power.

B. *Fender:*

Piece of curved metal covering a part of wheel to protect the cyclist from being splashed.

C. *Front Brake:*

Mechanism activated by brake cable compressing a calliper of return springs. It forces a pair of brake pads against the sidewalls to stop the bicycle.

D. *Hub:*

Centre part of the wheel from which spoke radiate, inside the hub are ball bearings enabling to rotate around in axle.

E. *Bevel gear:*

A kind of gear in which the two wheels working together lie in different planes and have their teeth cut at right angles to the surfaces of two cones whose apices coincide with the point where the axes of the wheels would meet.

F. *Driven Shaft:*

A shaft-driven bicycle is a bicycle that uses a drive shaft instead of a chain to transmit power from the pedals to the wheel. Shaft drives were introduced over a century ago, but were mostly supplanted by chain-driven bicycles due to the gear ranges possible with sprockets and derailleurs. Recently, due to advancements in internal gear technology, a small number of modern shaft-driven bicycles have been introduced.

G. *Bearing:*

For the smooth operation of Shaft, bearing mechanism is used. To have very less friction loss the two ends of shaft are pivoted into the same dimension bearing.

H. *Merits of Drive Shaft:*

1) They have high specific modulus and strength.
2) Reduced weight.
3) Due to the weight reduction, energy consumption will be reduced.
4) They have high damping capacity hence they produce less vibration and noise.
5) They have good corrosion resistance.
6) Greater torque capacity than steel or aluminium shaft.
7) Longer fatigue life than steel or aluminium shaft.
8) Lower rotating weight transmits more of available power.

I. *Selection of Bevel Gear:*

Bevel gears are gears where the axes of the two shafts intersect and the tooth-bearing faces of the gears themselves are conically shaped. Bevel gears are most often mounted on shafts that are 90 degrees apart, but can be designed to work at other angles as well. The pitch surface of bevel gears is a cone. Two important concepts in gearing are pitch surface and pitch angle. The pitch surface of a gear is the imaginary toothless surface that you would have by averaging out the peaks and valleys of the individual teeth. The pitch surface of an ordinary gear is the shape of a cylinder. The pitch angle of a gear is the angle between the face of the pitch surface and the axis.The most familiar kinds of bevel gears have pitch angles of less than 90 degrees and therefore are cone-shaped. This type of bevel gear is called external because the gear teeth point outward. The pitch surfaces of meshed external bevel gears are coaxial with the gear shafts; the apexes of the two surfaces are at the point of intersection of the shaft axes.

IV. Working Principle

The job involved is the design for suitable drive shaft and replacement of chain drive smoothly to transmit power from the pedal to the wheel without slip. It needs only a less maintenance. It is cost effective. Propeller shaft strength is more and also propeller shaft diameter is less. It absorbs the shock. Because the propeller shaft center is fitted with the universal joint is a flexible joint. It turns into any angular position. The both end of the shaft are fitted with the bevel pinion, the bevel pinion engaged with the crown and power is transmitted to the rear wheel through the propeller shaft and gear box. With our shaft drive bicycle, there is no more grease on your hands or your clothes; and no more chain and derailleur maintenance.

V. Design Assumptions

1) The shaft rotates at a constant speed about its longitudinal axis.
2) The shaft has a uniform, circular cross section.
3) The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the Geometric center.
4) All damping and nonlinear effects are excluded.
5) The stress-strain relationship for composite material is linear & elastic; hence, Hooke's law is Applicable for composite materials.
6) Acoustical fluid interactions are neglected, i.e., the shaft is assumed to be acting in a vacuum.
7) Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane Stress.

VI. Calculations

A. *Design calculation of gear*

Speed of gear (N_g) = 100rpm
Velocity ratio (i) = 4
Teeth of pinion (Ze) = 8
Mass of rider (m) = 85 kg
Inner diameter of pinion = 33mm
Outer diameter of pinion = 41mm
Inner diameter of crown = 92mm
Outer diameter of crown = 132mm
Length of pedal leaver = 190mm

1) Maximum torque applied on bicycle

Torque = weight of rider * length of pedal leaver
T = m*g*L
T = 85*9.81*0.190
T = 158.4315 N-m

2) Rated power (P)

$P = 2*\pi N*T/ 60$
$P = 2*100*\pi*158.4315/60$
P = 1.6590 KW

3) Design power (P_d)

$P_d = K_L * P$
= 1.25*1.6590
= 2.073875 KW

4) Select suitable teeth of crown

$Z_p = 8$
$i= Z_c / Z_p = Np / Nc$
$4 = Z_c / 8 = Np / 100$
$Z_c = 32$
$N_p = 400$ rpm

5) Pitch angle (γ)

For pinion
$\tan\gamma_p = Zp / Zc$
$\tan\gamma_p = 8 / 32$
$\gamma_p = 14.036$
Similarly for crown
$\tan\gamma_c = 32 / 8$

γ_c = 75.9637

6) Module (m)

Diameter = module * teeth

41 = m*8

m = 5.125mm

Normal module (m_n)

m_n = 5 mm

m_n = m*cosβ

5 = 5.125 * cosβ

β = 12.68

7) Cone distance (Lc)

L = 0.5* √(Dp^^{2} + Dc^^{2})

L = .5* √(132*132 + 41*41)

L = 69.11mm

8) Pitch circle diameter (P_c)

Pc = πm

Pc = π*5.125

Pc = 16.1mm

9) Normal pitch diameter (P_n)

Pn = π*m_n

Pn = π*5

Pn = 15.70mm

10) Virtual number of teeth (Z_e)

For crown

Z_e)c = Zc / (cosβ)^3

Z_e)c = 33/(cos12.68)^3

Z_e)c = 35.537

Z_e)c = 36

For pinion

Z_e)p = Zp / (cosβ)^3

= 8/(cos12.68)^3

Z_e)p = 9

11) Tangential force (Ft)

Ft = 1000*P_d *Cv /V

Velocity

V = π D*N/60

V = π*400*0.041/60

V = 0.857 m/s

For medium shock of service foctor

Cs = 1.50

Ft = 1000*2.0986*1.5/ 0.8587

Ft = 3.6658KN

12) Beam strength

Lewis equation

Ft = σ_d *Cv*b*Y*m_n /C_w

for velocity less then 5m/s

Cv = 4.5/(4.5+V)

Cv = 4.5/(4.5 +.8587)

Cv = 0.8421

Y = y*π

Where y = lewis form fector

For ϕ = 20 full depth

y = o.154 – 0.912/ Ze

y = 0.0526

Y = y*π

Y = 0.1654

Wear and lubrication factor

C_w = 1.25

$Ft = \sigma_d * Cv*b*Y*m_n / C_w$
3.6658 = 78.5*1000*0.8441*5*0.1654*b/1.25
b = 83.8mm
check face width of helical gear
$b = 12.5m_n$ to $20m_n$

13) Dynamic load calculation

$F_d = Ft + Fi$
$F_d = Ft + K_3 * V (C*b + Ft) / K_3 * V \sqrt{(C*b + Ft)}$
Where,
F_d C = dynamic load factor
$C = e / K_1 (1/E_1 + 1/E_2)$
$K_1 = 9$ For 20deg. Full depth
$K_3 = 20.67$
For C35 E = 490 to 580 N/ mm^2
For m = 5, e = 0.0555
So,
C = 0.0555 /[9*(2/540)]
C = 1.6495
So dynamic load
F_d =3665.8+20.67*.8587*(1.6495*0.083+3665.8)/[20.67*0.8587+√(1.6495*0.083+3665.8)]
F_d = 4496.847 N

14) Wear load calculation

$F_w = d_1 bQK \geq F_d$
Where,
K = load stress factor
$K = \sigma_{es}^2 \sin\alpha (1/E_1 + 1/E_2) / 1.4$
σ_{es} = surface endurance limit of gear pitch
σ_{es} = 2.75(BHN) – 70
= 2.75*300 -70
σ_{es} = 755 N/mm^2
So K = 755^2 *sin20(2/540)/1.4
K = 515.76
$Q = 2Z_2 / (Z_1 + Z_2)$
Q = 2*33/(33+8)
Q = 1.609
Therefore,
$F_w = d_1 bQK \geq F_d$
F_w = 41*83*1.609*515.76
$F_w = 2.808*10^6$ N
Here ,
$F_w \geq F_d$

Design of shaft

Power (P)	= 2.34 kW = 2.34 x 103 W
Speed (N)	= 400 rpm
Mass (m)	= 85 kg
Weight of 1st pinion (W_A)	= 9 N
Weight of 2nd pinion (W_B)	= 5 N
R_B	= 24 mm
Tensile stress (Syt)	= 296 mPa
Shear stress (**τ**)	= 0.35 x Syt

= 103.2 mPa
Assume,
Fatigue factor,
Km = 1, Kt = 0.5
Torque applied,
T = (P x 60) / (2π x N)
= (2.0738 x 10^3 x 60) / (2π x 400)
T = 49.50 N-m
T = 49.50 x 10^3 N-mm

Total vertical load acting downward on the shaft at A,
$F_{t\,A} = (T / R_A)$
$= (49.50 \times 10^3) / (36.85)$
= 1343.28N
Since the weight of gear A at vertically downward therefore the total vertically acting upward of the same shaft at A
$= F_{t\,A} – W_A$
= 1343.28 – 9
= 1334.28 N
Assuming that the torque on the gear B in same as that of the shaft therefore the tangential force acting vertically upward on the same gear B,
$F_{t\,B} = (T / R_B)$
$= (49.50 \times 10^3) / (24)$
$F_{t\,B}$ = 2062.5 N
Since the weight of gear B at vertically downward therefore the total vertically acting upward of the same shaft at B
$= F_{t\,B} - W_B$
= 2062.5 – 5
= 2057.5 N
Taking moment about D we get,
R_C x 300 = 1334.28 x 360 + 2057.5 x 50 - 14x 155
R_C = 1936.819 N
For the equilibrium of the shaft,
1334.28 + R_D = R_C + 2062.5 + 14
R_D + 1334.28 = 1936.819 + 2062.5+ 14
R_D = 2679.04 N
SFD calculation,
A_L = 0 N
A_R = 1334.28 N
C_L = 1334.28 N
C_R = 1334.28 – 1936.819
= -602.539 N
E_L = -602.539 N
E_R = -602.539 – 14
= -616.539 N
D_L = -616.539 N
D_R = -616.539 + 2679.04
= 2062.5 N
B_L = 2062.5 N
B_R = 2062.5 - 2062.5
= 0 N
We know that bending moment at A and B = 0
BM at C
M_c = 1936.819 x 60
$= 116.209 \times 10^3$ N-mm
BM at E
M_E = 1334.28 x 205 – 1936.819 x 145
$= -7.311 \times 10^3$ N-mm
BM at D
M_D = -2062.5 x 50
$= -103.125 \times 10^3$ N-mm
We see that the bending moment is maximum at C
Maximum Bending Moment
$M = M_C = 116.209 \times 10^3$ N-mm
We know that the equivalent twisting moment
$Te = \sqrt{[(Km * M)^2 + (Kt * T)^2]}$
$Te = \sqrt{[(1 * 116.209 \times 10^3)^2 + (0.5 * 49.50 \times 10^3)^2]}$
$Te = 118.815 \times 10^3$ N-mm
Also, we know that the equivalent twisting moment (Te)
$Te = (\pi / 16) \times \boldsymbol{\tau} \times d^3$
$118.815 \times 10^3 = (\pi / 16) \times 103.2 \times d^3$

d = 18.03 mm
Therefore,
Diameter of shaft = 18.03 mm
Now consider mass (m) acting on shaft = mass of shaft (1.3 kg) + mass of two bearing (0.8+0.6 kg) = 2.7 kg

1) Mass moment of inertia (I) = m x R^2
   = 2.7 x (0.01053)2
   = 0.00299 kg-m2
2) Polar movement of inertia (J)
   J = (π / 32) x d^4
   J = (π / 32) x 0.01803
   J = 1.0378 x10-8 m^4

VII. ADVANTAGES AND APPLICATIONS

A. *Advantages*

1) Drive system is less likely to become jammed.
2) The use of a gear system creates a smoother and more consistent pedaling motion.
3) Lower maintenance.
4) Efficiency is more as compared to conventional bicycle design.
5) High durability.
6) Low cost of ownership when manufactured in large scale.

B. *Applications*

1) It is used for racing purpose.
2) Also used for Off-road riding.
3) For Cycling.
4) For public and bicycle rental purpose.

VIII. RESULT AND CONCLUSION

1) The presented work was aimed to reduce the wastage of human power on bicycle riding.
2) The presented work also deals with optimization i.e. converting rotary motion into the linear motion with aid of two bevel gears.
3) Instead of chain drive one piece drive shaft for rear wheel drive bicycle have been optimally designed and manufactured for easily power transmission.
4) The result obtained from this work is a useful approximation to help in the earlier stage of the development, saving development time and helping in the decision making process to optimize a design.
5) Hence we are trying to make the transmission smooth and easy by applying the bevel gears and shaft attachment instead of chain, chain sprocket.
6) The results obtained from this work is an useful approximation to help in the earlier stages of the development, saving development time and helping in the decision making process to optimize a design.
7) The drive shaft has served as an alternative to a chain-drive in bicycles for the past century, never becoming very popular.

IX. TROUBLESHOOTING

When abnormal vibrations or noises are detected in the driveshaft area, this chart can be used to help diagnose possible causes.

Table – 1
TROUBLESHOOTING

Problem	*Caused by*	*What to do*
As bicycle is accelerated from stop	*torque is required*	*Apply more torque at starting*
when gears are not shifting	*rusting*	*Clean with fluids*
Vibration at speed	*High speed*	*Maintain low speed*
Noise at low speed	*Universal joint*	*Apply grease*
Gears pitch circle is not coincide	*Vibrations*	*Adjust the position of gears*
Gear backlash	*Noise, Overloading, Overheating*	*Follow design characteristics*

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