# A REVIEW OF DIFFERENT DESIGN CONFIGURATIONS OF SHAFT-DRIVEN BICYCLES

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***Abstract: A shaft-driven bicycle uses a drive shaft instead of a chain to transmit power from the pedal crankshaft to the wheel arrangement. Shaft-drives were introduced a century ago, but were mostly replaced by chain-drives due to gear ranges possible with sprockets and derailleur. Shaft drives are difficult to disassemble when repairing flat rear tires and have higher manufacturing costs. Both high quality gears and heavier frame construction are required for shaft-drives. Most advantages claimed for a shaft drive can be realized by using a fully enclosed chain case. The unique major advantage of shaft drive is that it operates at a very consistent rate of efficiency and performance. That too without adjustments or maintenance. Since, shaft-drives require gear hubs for shifting, the gears can be shifted while the bicycle is at a complete stop or moving in reverse. Also recent advancements in internal gear technology has led a small number of modern shaft-driven bicycles to be introduced. Due to above reasons shaft-drive configurations are worth studying. As a result, various design configurations of bicycle shaft-drive are reviewed. A design configuration that meets all the requirements is suggested, based on the type of gears used, ease in gear shifting, etc. Out of different design configurations, shaft-driven bicycle with straight bevel gears seems to offer greatest flexibility in design.***

***Keywords: shaft-driven, bicycle, chain-driven, drive-shaft, straight bevel gears, spiral bevel gears***

## I. INTRODUCTION

A shaft-driven bicycle uses a drive shaft instead of a chain to transmit power from the pedal crankshaft to the wheel arrangement. Shaft-drives were introduced a century ago, but were mostly replaced by chain-drives due to gear ranges possible with sprockets and derailleur. Shaft drives are difficult to disassemble when repairing flat rear tires and have higher manufacturing costs. Both high quality gears and heavier frame construction are required for shaft-drives. Most advantages claimed for a shaft drive can be realized by using a fully enclosed chain case. The unique major advantage of shaft drive is that it operates at a very consistent rate of efficiency and performance. That too without adjustments or maintenance. Since, shaft-drives require gear hubs for shifting, the gears can be shifted while the bicycle is at a complete stop or moving in reverse. Also recent advancements in internal gear technology has led a small number of modern shaft-driven bicycles to be introduced. Due to above reasons shaft-drive configurations are worth studying. As a result, various design configurations of bicycle shaft-drive are reviewed. A design configuration that meets all the requirements is suggested, based on the type of gears used, ease in gear shifting, etc. Out of different design configurations, shaft-driven bicycle with straight bevel gears seems to offer greatest flexibility in design. Shaft-driven bikes have a large bevel gear in place of chain ring of a conventional bike. 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°. 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.

Figure 1: A sketch of a safety bicycle

## II. BICYCLE PARTS

A bicycle frame is the main component of a bicycle. Wheels and other components are fitted on the frame. The modern and most common frame design, known as diamond frame, is based on safety bicycle (Figure 1). It comprises of a main triangle and a paired rear triangle. The main “triangle” is not a true triangle because it consists of four separate tubes, namely, head tube, top tube, down tube and seat tube. The rear triangle is made of the seat tube joined by paired chainstays and seatstays. The head tube contains the headset, the interface with the fork. The top tube connects the head tube to the seat tube at the top. The down tube connects the head tube to the bottom bracket shell. The rear triangle is connected to the rear fork ends. A bicycle pedal (Figure 2) is the part of the bicycle that the riders push with their foot to propel the bicycle. Pedals usually consists of a spindle that threads into the end of the crank and a body.

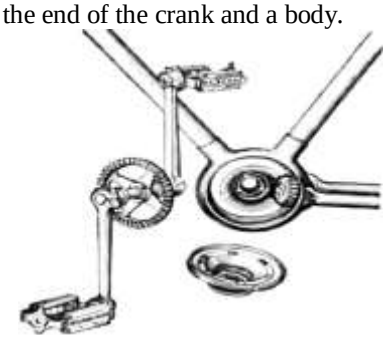


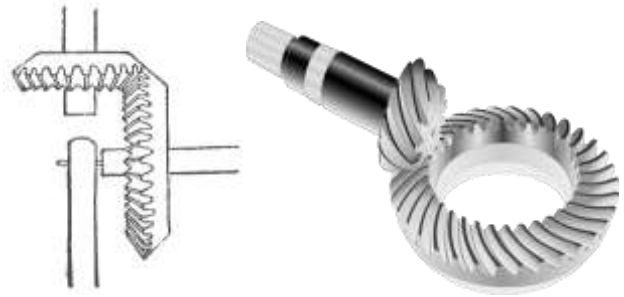
Figure 2: A sketch of pedal crank mounted on ring bevel ring and drive shaft bevel gear

The shaft used instead of a chain to transmit power from the pedals to the wheel is known as drive shaft. Centre part of the wheel from which spoke radiate is called as hub. Inside the hub are ball bearings enabling to rotate around in axle.

## III. MAJOR GEARS USED IN SHAFT DRIVES

Helical gears have their teeth are angled with respect to the axis of rotation at a helix angle. The teeth form a helix either right- or left-handed. Helical gears operate much more smoothly and quietly than spur gears. Because of the angle of the teeth on helical gears, a thrust load is created on the gear when they mesh. Devices that intend to use helical gears must have bearings in order to support this thrust load. A pair of opposite-hand helical gears mesh with their axes parallel. Same hand helical gears can be meshed with their axes skewed and are called crossed helical gears. Teeth of crossed helical gears slide instead of rolling. This greatly reduces their load-carrying capacity. Bevel gears (Figure 3) are cut on mating cones rather than the mating cylinders of spur or helical gears. Their axes are non parallel and intersect at the apices of the mating cones. The angle between their axes can be any value and is usually 90° in case of shaft drives. If the teeth are cut parallel to the cone axis, they are straight bevel gears, similar to spur gears. If the teeth are cut at a spiral angle to the cone axis, they are called spiral bevel gears, similar to helical gears. As compared to straight bevel gears, spirals are smaller in diameter for the same load capacity. Spirals are extreme in smoothness and quiet running. A worm set consists of a worm and a worm gear. They connect nonparallel, nonintersecting shafts, usually at right angles to one another. The worm is similar to a screw thread and the worm gear is analogous to its nut. The ability to provide high ratios in a compact package is one of the major advantages of a worm set over other gearing configurations. Another advantage of worm sets is their ability to self lock. Its main disadvantage is its relatively low efficiency as compared to other gear sets.



(a) (b)

Figure 3: Sketches of (a) straight bevel gear (b) spiral bevel gear

## IV. DESIGN CONFIGURATIONS OF DRIVE SHAFTS

The number of patents granted yearwise of the literature review done so far are shown in Figure 4. The figure shows that the years between 1890 to 1904 showed a lot of interest in chainless bicycle, which declined till 1974. Then the inventors showed renewed interest in years between between 1974 to 2015.

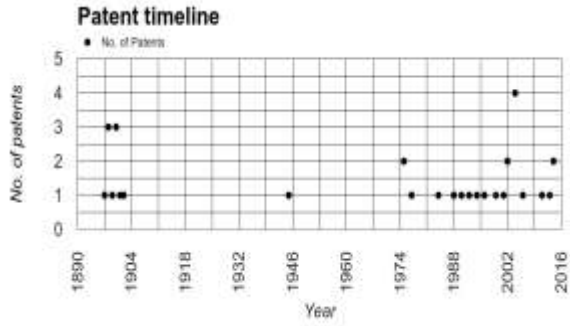



Figure 4: Patent distribution

The developments in chainless drive mechanisms for bicycles are summarized in Table 1. Most inventions focused on use of drive shafts with bevel gears with exception of few inventors who presented designs based on mechanisms other than bevel gears. Shryock, 1898 patented a mechanism employing twin eccentrics for driving the rear wheel. An eccentric was provided for each pedal. Olson et al., 1899 presented a mechanism employing slider-crank and spiral cam that transmitted power to rear wheel through bevel gears. A slider crank and rack bar mechanism was introduced by Shellabarger, 1900 while Booth, 1902 introduced a chain and four bar drive mechanism. Chiu, 1990 designed a complex mechanism that used gears other than bevel gears. A drive mechanism using reciprocal rectilinear pedal motion to propel a pinion gear against a crown gear was patented by Doroftei, 2001. Finally, Haan, 2014 designed a drive mechanism involving two drive systems, one for front and the other for rear wheel. The rest of the inventors focussed on various aspects of shaft-drive mechanism involving power transmission using gears with perpendicular shafts like bevel gears. Slusser, 1898, Cairns, 1990, Mendoza, 1975, Hsu, 1996 and Pogson, 2000 worked on single speed single shaft-drive using straight bevel gears for power transmission. Chuan-Sheng Lin and Wei Lii, 1988 designed single speed single shaft-drive using spiral gears. Cellini (2002) designed similar drive using worm gear at each end. Chang, 2002 used helical gears for the same configuration. Weaver et al., 2004 used an epicyclic gear train in addition to bevel gears. Single speed twin shaft-drive designs using straight bevel gears were introduced by Watson, 1949, Keyes, 1992, Bell, 1994 and Samuel O. Smith and William J.T. Fleet, 2006. Chang, 2004 presented a derailleur system for bicycle for single drive shaft. Liu, 2004 addressed the problem of converting existing bicycles with chain drives into shaft drives by developing a fitting type mechanism. The proposed mechanism used single drive shaft and speed adjustment mechanism for existing chain-drive bicycles. In multi-speed drives, David C. Leob and Robert Trestman, 1975 developed a multi speed drive using a shiftable drive shaft having multitude of concentric series of gear teeth. Another multi speed drive using a pair of discs each with inbuilt concentric series of openings mounted on the pedal crankshaft and rear wheel respectively was developed by Jefferies, 1977. Brooks, 1984 provided a solution for automatic shifting of gears in response to load demands. Hahn, 2004 presented a new method to lift the drive shaft

gear off of one ring of gears and to set it down onto another ring of gears using a variable length drive shaft. Unlike single speed drives bevel gears were preferred in multi speed drives.

Table 1: Timeline of inventions

| Inventor(s) | Description (patent no., year of patent) |
|---|---|
| Shryock | Twin eccentrics (607710, 1898) |
| Slusser | Single drive shaft with bevel and spur gears at ends (609471, 1898) |
| Olson et al. | Slider-crank, spiral cam and straight bevel gear (622780, 1899) |
| Shellabarger | Slider crank and rack bar mechanism (642013, 1900) |
| Cairns | Single drive shaft with bevel gears (650779, 1900) |
| Booth | Chain and four bar mechanism (709463, 1902) |
| Watson | Complex bevel gear mechanism with twin drive shafts contained inside the rear fork tubes (2475654, 1949) |
| Mendoza | Direct transmission system using bevel gears (3861715, 1975) |
| David C. Leob and Robert Trestman | Multi Speed drive with shiftable drive shaft using multitude of concentric series of bevel gear teeth (3863503, 1975) |
| Jeffries | Multi Speed drive using a pair of discs, each with inbuilt concentric series of openings mounted on the pedal crankshaft and rear wheel, respectively (4005611, 1977) |
| Brooks | Automatic gear shift in response to load demands using disc gear with plurality of radial grooves (4447068, 1984) |
| Chuan-Sheng Lin and Wei Lii | An enclosed single-axle driving mechanism comprised of one pair of spiral driving gears and one pair of spiral driven gears for power transmission. (4943077, 1988) |
| Chiu | A driving device without chain for bicycle comprises a driving wheel mounted to a crank shaft, a rear gear mounted to a wheel hub for mounting a rear wheel of the bicycle, an input gear coupled with the driving wheel by means of an interconnecting link and a gear set having two identical gears respectively engaging the rear gear and the input gear. (5002296, 1990) |
| Keyes | Twin drive shaft with bevel gears (5078416, 1992) |
| Bell | A pair of hollow support tubes each carrying a drive shaft with bevel gears at each end. (5316327, 1994) |
| Hsu | Single drive shaft with bevel gears (5482306, 1996) |
| Chang | Single drive shaft using helical gears (5967537, 1999) |
| Pogson | Single drive shaft with bevel gears (6155127, 2000) |
| Doroftei | Drive mechanism using reciprocal rectilinear pedal motion to propel a pinion gear against a crown gear (US6199884B1, 2001) |

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|---|---|
| Cellini | Single drive shaft with worm-gear at each end (US6394477B1, 2002) |
| Chang | Single drive shaft-transmission assembly has a transmission shaft, a drive gear, a front gear, a rear gear and a driven gear using helical gears (US6478323B2, 2002) |
| Hahn | New method to lift the drive shaft gear off of one ring of gears and to set it down onto another ring of gears. Using an extendible and retractable (i.e. variable length) drive shaft. A number of concentric sets of bevel gear teeth. (US2004/0083839A1, 2004) |
| Weaver et al. | Single drive shaft using bevel gears and epicyclic gear train with ring gear positioned to mesh with corresponding planet gears (US6685205B1, 2004) |
| Chang | Presented a derailleur system for bicycle for single drive shaft and ring sprocket gears (US755431B2, 2004) |
| Liu | Fitting type single drive shaft and speed adjustment mechanism for existing bicycles with chain transmission using bevel gears (US6814365B2, 2004) |
| Samuel O. Smith and William J.T. Fleet | Twin shaft with front and rear bevel gears (US6986520B2, 2006) |
| Hotoda | Rear wheel drive using two spur gears for slopes and level road (US8056917B2, 2011) |
| Souvanny | Twin ring gears, bevel gears enclosed in a triangular casing; hubless tyres (US8414006B2, 2013) |
| Haan | Two independent drive systems with hand pedalled front wheel drive and foot pedalled rear wheel drive. Less exposed moving parts without chains, sprockets or derailleurs. (US2014/0125032A1, 2014) |
| Williams | Rear drive with twin spur gears (US8651505B2, 2014) |

## V. CONCLUSION

Since, non-parallel intersecting shafts usually at right angle are used in shaft-driven bicycles, helical gears, bevel gears and wormset are important types of gear sets for such drives. Though same hand helical gears satisfy above requirement but have reduced load carrying capacity due to presence of sliding friction. Both straight and spiral bevel gears are suitable for shaft driven bicycle. Smaller spiral bevel gears are required for same load capacity and are smooth and quiet running when compared to straight bevel gears. On the other hand, straight bevel gears offer advantage of convenient gear shifting. Wormset (worm and worm wheel) is capable of providing highest gear ratio among all other gear types in a compact package. But they have low efficiency due to presence of sliding friction. Straight bevel gears are favoured by most inventors for single drive shaft mechanisms but few inventors preferred using spirals due to advantages discussed above. But in case of multi speed shaft drives almost all inventors used straight bevel gears as they have advantage of easy gear shifting. In author's opinion and in view of above the design configuration employing spiral bevel gears should be preferred for single speed shaft drives. Wormset may also be used for single speeds but only secondary to spirals. Straight bevel gears are recommended for multi-speed shaft drives due to ease in gear shifting.

## REFERENCES

[1] Bell J.H., 1994, Chainless bicycle with dual drive shafts and floating drive train suspension system, US Patent No. 5316327.
[2] Booth F., 1902, Chainless bicycle, US Patent No. 709463.
[3] Brooks L.E., 1984, Bicycle drive mechanism, US Patent No. 4447068.
[4] Cairns W., 1900, Chainless bicycle, US Patent No. 650779.
[5] Cellini V., 2002, Chainless bicycle drive system, US 6394477 B1.
[6] Chang C-C, 1999, Chainless transmission mechanism for a bicycle, US Patent No. 5967537.
[7] Chang S-Hsing, 2002, Transmission device for a chainless bicycle, US Patent No. US 6478323 B2.
[8] Chang Y-C, 2004, Derailleur system for bicycle, US Patent No. US 6755431 B2.
[9] Chiu Y-T, Tsun T-S, Hsiang H-S and Hsien T., 1991, Driving device for bicycle, US Patent No.

  

5002296.
[10] Doroftei M., 2001, Helical drive bicycle, US Patent No. US 6199884 B1.
[11] Hahn T.L., 2004, Simple bicycle drive shaft transmission, US Patent No. US 2004/0083839 A1.
[12] Hann K.D., 2014, Dual drive bicycle, US Patent No. US 2014/0125032 A1.
[13] Hotoda H., 2011, Bicycle, US Patent No. US 8056917 B2.
[14] Hsu S-H, 1996, Chainless transmission mechanism for bicycles, US Patent No. 5482306.
[15] Jefferies W.E., 1977, Chainless bicycle drive mechanism, US Patent No. 4005611.
[16] Keyes K.S., 1992, Drive-shaft driven bicycle, US Patent No. 5078416.
[17] Leob D.C. and Trestman R., 1975, Multispeed, chainless vehicle drive system, US Patent No. 3863503.
[18] Liu J-C, 2004, Fitting type chainless transmission and speed adjustment mechanism of bicycle, US Patent No. US 6814365 B2.
[19] Lin C-S and Lii W., 1990, Enclosed single-axle driving mechanism for bicycles, US Patent No. 4943077.
[20] Mendoza H., 1975, Direct transmission system for bicycles, US Patent No. 3861715.
[21] Olson O.N., Smith C.H. and Belina W.C., 1899, Chainless bicycle, US Patent No. 622780.
[22] Pogson D.D., 2000, Chainless drive mechanism, US Patent No. 6155127.
[23] Robert L. Norton, (2000). Machine Design An Integrated Approach, 2nd. Ed. Pearson Education, 755-796.
[24] Shryock W.T., 1898, Chainless bicycle, US Patent No. 607710.
[25] Slusser B.E., 1898, Chainless bicycle-gearing, US Patent No. 609471.
[26] Schoenthal F.C. , 1900, Chainless bicycle, US Patent No. 653968.
[27] Shellabarger J., 1900, Driving mechanism for bicycles, US Patent No. 642013.
[28] Smith S.O. and Fleet W.J.T., 2006, Shaft driven bicycle and transmission therefor, US Patent No. US 6986520 B2.
[29] Souvanny N., 2013, Bicycle device with direct drive transmission and hubless wheels, US Patent No. US 8414006 B2.
[30] Watson R.A., 1949, Chainless bicycle drive, US Patent No. 2475654.
[31] Weaver B.L., Weaver B.R.R. and Sutton B., 2004, Multi-speed inline bicycle transmission, US Patent No. US 6685205 B1.
[32] Williams M., 2014, Bicycle, US Patent No. US 8651505 B2.

  