

Study of Drive Mechanisms of Bicycle, Tricycle or Like Vehicles to Optimize Operating Performance - A Review

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ABSTRACT

A cycle or cycle rickshaw is a small-scale local means of transport. Cycle rickshaws are human-powered, a type of tricycle designed to carry passengers in addition to the driver. Tricycles are used primarily for commercial transportation. Various locally made configurations of bicycle or tricycle are available. The present form of cycle has many shortcomings. One of the major problems faced by available bicycle or tricycle is its less efficiency or mechanical advantage. This paper reviews patent (which are now open for public access) and experimental work brought by researchers on drive mechanism of cycle in order to optimize its operating performance. An individual idea or any possible combination of different ideas can be used for optimizing performance of driving mechanism for cycle.

Keywords- Cycle, Mechanical advantage, Drive mechanism, Sprocket, Chain.

I. INTRODUCTION

A cycle is widely used local means of transport. One of the forms of cycle is tricycle, also known as cycle rickshaw. Most cycle rickshaws used to carry passengers for hire. These vehicles are widely used in South Asia and Southeast Asia, where rickshaw driving provides essential employment for recent immigrants from rural areas, generally impoverished men. Various locally made configurations of cycle are used across world. In an eco-sensitive zone where motor vehicles are banned, man-pulled cycles are still one of the major forms of transport there.

Besides this, the present cycle has many shortcomings. One of the major problems faced by available cycle is its less efficiency or mechanical advantage. Many researches are carried out for improving efficiency of drive mechanism of bicycle, tricycle or like vehicles.

1.1 Mechanical Advantage

Mechanical advantage (M.A.) is a measure of the amplification of particular parameter, achieved by using a tool, mechanical device or machine system. In simple words M.A. means getting the thing done at lesser effort. Ideally, the device preserves the input power and simply trades off forces against movement or no. of rotation. In case of cycle, amplification of force on pedal, no. of rotation of wheel is done in order to increase efficiency or mechanical advantage. There are two possible ways to measure mechanical advantage. These are as follows-

- [1] More distance travelled by cycle but keeping magnitude of applied force (on pedal) same.
- [2] Same distance travelled by cycle, at less force applied on pedal.

1.2 In case of chain drive

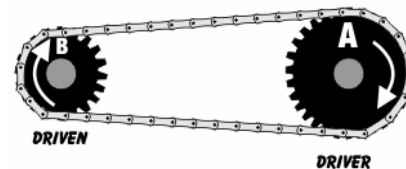


Figure 1: Simple chain drive mechanism

$$M.A. = V.R. = NB/NA \quad \dots\dots\dots (1)$$

Where,

M.A. = Mechanical Advantage.

V.R. = Velocity Ratio.

NA, NB = Number of rotation of sprocket wheel A and B respectively.

So, if we able to increase V.R. we will get more M.A. i.e. more efficient drive.

II. RELATED WORK

There are many patented and experimental work available to optimize performance of drive mechanism of bicycle, tricycle or like vehicles. Also some research articles are published in journal with same objective as above. Some researcher focuses on reducing the force required to apply on pedal to propel the cycle. Besides this, some researcher focuses on increasing the number of rotations of rear wheel of cycle by keeping the force required to apply on pedal as it is. With these two broad views, we can understand that force required to apply on pedal and

number of rotations of rear wheel are two most important parameters, that affects the performance of drive mechanism of cycle.

2.1 Erickson et al. [1] have performed a patented work on improving drive mechanism efficiency of cycle by changing diameter of drive sprocket. As stated earlier, drive mechanism efficiency or mechanical advantage increases with increase in velocity ratio. Referring to figure (1) and equation (1), we can also write as-

$$M.A. = V.R. = NB/NA = DA/DB$$

Where,

DA, DB = Diameter of sprocket wheel A and B respectively.

Hence, by increasing diameter of drive sprocket, we get higher velocity ratio and ultimately higher drive mechanism efficiency or mechanical advantage.

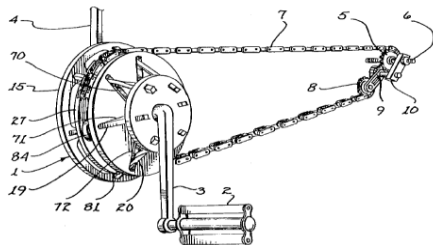


Figure 2: Variable gear ratio chain drive system.

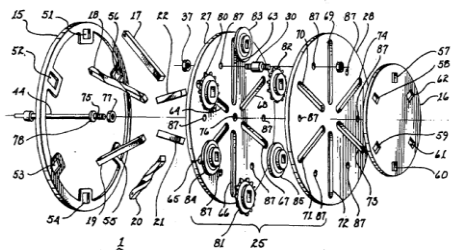


Figure 3: Exploded pictorial view of the elements illustrated in figure (2).

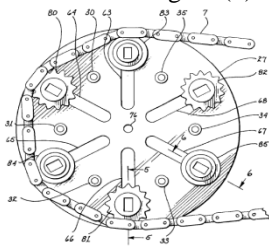


Figure 4: Side view of the drive sprocket assembly

A drive mechanism [see Figure (2)] developed by Erickson et al. incorporates a drive sprocket assembly having a plurality of radially displaceable sprocket gears [see Figure (4)]. Each of the sprocket gears is mounted upon a shaft extending intermediate two spaced apart plates [see Figure (3)]. Each shaft has a unique degree of radial displacement and twist intermediate the plates which are

respectively, commensurate with the finite range of effective diametric excursion and resulting change in effective circumference of the drive sprocket assembly. The effective diameter of the drive sprocket assembly is variable by translating the drive sprocket intermediate the fixed plates and forcing the sprocket gears to extend to contract radially along their respective shafts. This positioning is affected by either pulling or pushing upon knob [not shown] which results in translation of linkage to draw intermediate plate towards or away from base plate.

2.2 Lawrence R. Gardner [2] have performed a patented work or invention related to a novel automatic chain tensioning unit. The usual configuration of chain drive system [see Figure (1)], while being of simple and efficient design, has its problems, some of which are elongation of the drive chain by wear, and by wear of the drive and driven sprocket. This result in a loosening of the drive chain which then tends to skip over the drive or driven sprocket, when the unit is under operating load. This creates a need for a drive chain take-up or tensioning unit to eliminate this common problem. Several of the more common types of drive chain take-ups are the sliding shaft arrangements. In cases where this method is impractical because of shaft alignment in the equipment involved, an external idler sprocket can be used. But the idler sprocket's use is limited to single directional drives only.

The chain tensioning unit developed by Gardner can be used on chain drives which are reversible or nonreversible, vertical, horizontal or inclined.

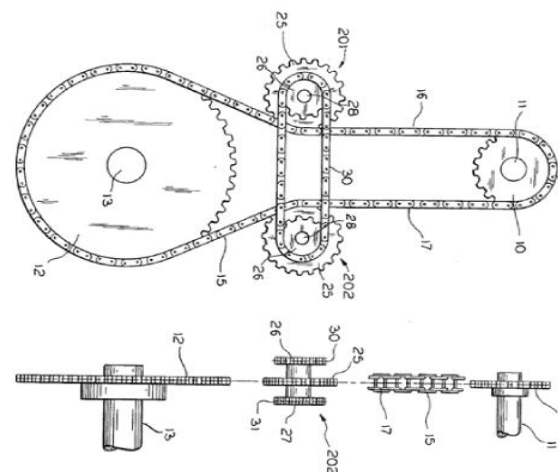


Figure 5: Chain drive & Automatic chain tensioning unit

An automatic drive chain tensioning unit developed by Gardner [see Figure (5)] comprises a pair of idler assemblies. Each of these idler assemblies comprises an idler sprocket and an indexing sprocket. Each idler assembly is positioned on the outside of a drive chain loop on a chain run

between a drive and driven sprocket. The idler sprocket is engaged in the drive chain and with the idler assemblies on different and opposite spaced-apart drive chain runs; and a pair of indexing chain loops, each one of which is adapted to engage an indexing sprocket on each of the spaced-apart idler assemblies on the same side of the drive chain.

2.3 Kenneth S. Keyes [3] 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 bicycles.

A number of problems may be associated with traditional coaster or 3-speed bicycles chains. They are subjected to slippage if the length of the chain is not correctly adjusted. Because the chain is often at least partially exposed, clothing, grass, or other objects may become caught in the chain as the chain move past the objects. In addition, dirt & foreign matter can become lodged on the chain links & decrease the efficiency of the chain mechanism.

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. See Figure (6).

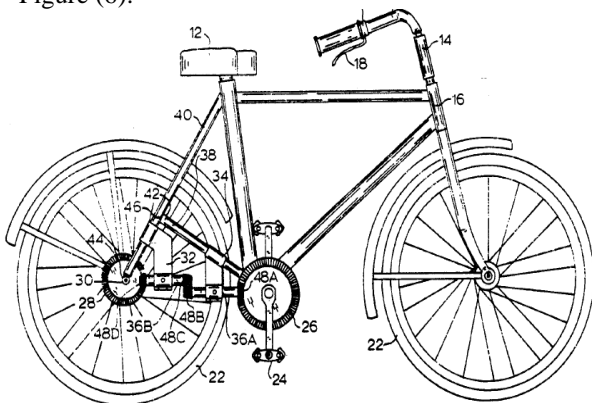


Figure 6: Perspective view of a bicycle constructed according to invention.

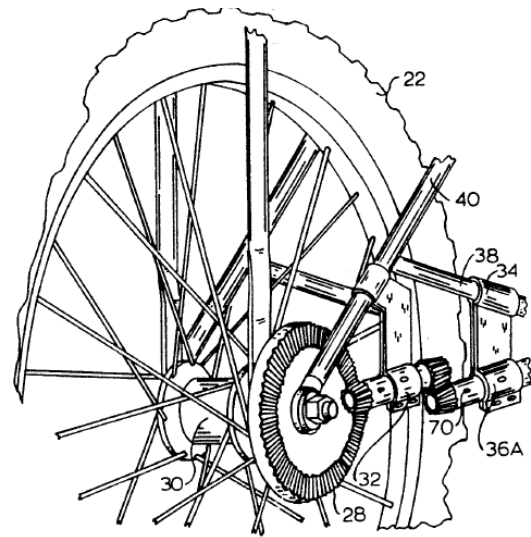


Figure 7: Perspective view of a portion of the drive shaft mechanism of the invention.

The major components of the preferred embodiment of the invention [see Figure (7)], that differ from previous bicycle were:

- [1] Replacement of the sprocket gears with bevel gears;
- [2] Replacement of the chain with a drive shaft;
- [3] A modified rear fork of the bicycle with attachment of brackets to hold the drive shaft in position;
- [4] Horizontally extended pedal shafts.

2.4 James B. Spicer et al. [4] have performed experimental study on the efficiency of bicycle chain drives under a variety of operating conditions and to explore the factors that govern chain drive efficiency. The efficiencies of bicycle chain drives was investigated both experimentally and theoretically to provide quantitative measurements of chain drive efficiency and to present models for power loss. These models for drive losses have been used to interpret experimental results. Assuming that the losses in the chain drive result from friction between contacting components that execute motion relative to one another, there are three significant sources for loss as follows:

- [1] Inner link bushing and chain pin
- [2] Chain line offset
- [3] Sprocket tooth, link roller and inner link bushing.

Tests of efficiency for the derailleur-type chain drive indicate that the overall efficiencies for the transfer of power from the front drive sprocket to the rear sprocket range from 80.9% to 98.6%. Primary factors affecting the efficiency include the sizes of the sprockets in the drive and the tension in the chain. It was found that larger sprockets provide more efficient transfer of power while smaller sprockets proved to

be less efficient. In frictional loss models a 2–5% loss difference was measured between the 52–11 and the 52–21 sprocket combinations depending on the drive operating conditions. Experimental results indicated that the efficiency varied linearly with the reciprocal of the average chain tension with the highest efficiencies occurring at high chain tensions and lowest at low chain tensions. It was found that chain line offset and chain lubrication has a negligible effect on efficiency under laboratory conditions. Infrared measurements of drive components indicate that frictional losses in the chain cause the chain temperature to rise during operation. This increase in temperature failed to provide significant correlation with losses under various operating conditions. These infrared measurements agreed with measured efficiency results. From the results it appears that the efficiency of the bicycle chain drive depends intimately on the chain operation as it engages and departs from the sprockets on the high-tension part of the drive. Owing to the high efficiencies measured under high chain tensions, friction can only account for a few percent of the overall losses. Mechanical losses that are not converted to thermal energy in the drive account for the remainder of the measured loss.

2.5 J.C. Martin et al. [5] have performed experimental study to determine the effects of cycle crank length on maximum cycling power, optimal pedaling rate, and optimal pedal speed, and to determine the optimal crank length to leg length ratio for maximal power production. The experiment has been performed using crank lengths of 120, 145, 170, 195, and 220 mm. The results obtained from experiment are shown in graph plots below.

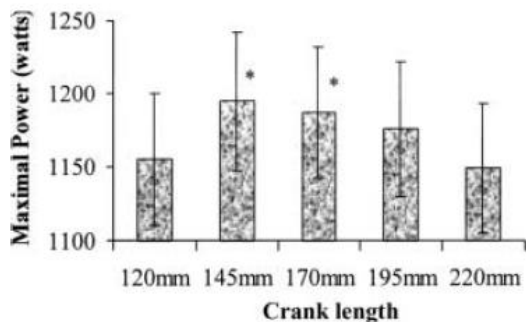


Figure 8: Maximum power versus crank length.

Figure (8) shows that maximum power varied by 4% across the range of crank lengths tested, from 1149 W for the 220-mm cranks to 1194 W for the 145-mm cranks. That is cycle crank lengths that varied by 83% elicited a mere 4% variation in maximum cycling power.

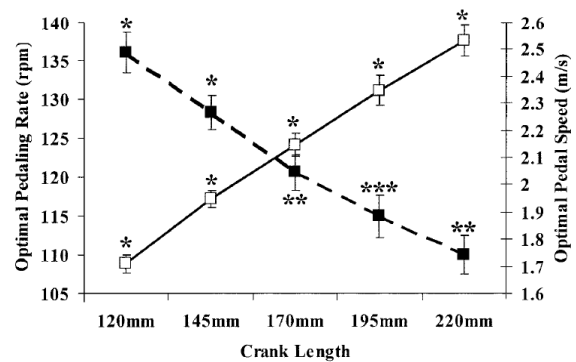


Figure 9: Optimal pedaling rate and optimal pedal speed. Where,

- (■): Optimal pedaling rate.
- (*): differs from all other crank lengths.
- (**): differs from all lengths except 195 mm. (***) differs from the 120- and 145-mm crank lengths.
- (□): Optimal pedal speed.

It is clear from figure (9) that, optimal pedaling rate decreased significantly with increasing crank length, from 136 rpm for the 120-mm cranks to 110 rpm for the 220-mm cranks. Conversely, optimal pedal speed increased significantly with increasing crank length, from 1.71 m/s for the 120-mm cranks to 2.53 m/s for the 220-mm cranks.

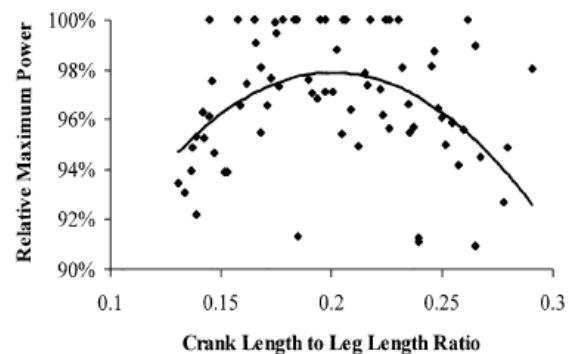


Figure 10: Maximum power versus leg length to crank length ratio.

See Figure (10). The crank length to leg length and crank length to tibia length ratios accounted for 20.5% and 21.1% of the variability in maximum power, respectively. The optimal crank length was 20% of leg length or 41% of tibia length. These data suggest that pedal speed and pedaling rate exert distinct effects that influence muscular power during cycling.

2.6 Paola Zamparo et al. [6] have performed experimental study on the mechanical efficiency of cycling with a new pedal–crank prototype (PP) using stationary cycloergometer. The efficiency values were compared with those obtained, in the same experimental conditions and with the same subjects, by using a standard pedal–crank system (SP). The

main feature of this prototype is that its pedal–crank length changes as a function of the crank angle being maximal during the pushing phase and minimal during the recovery one. This variability was expected to lead to a decrease in the energy requirement of cycling since, for any given thrust; the torque exerted by the pushing leg is increased while the counter-torque exerted by the contra-lateral one is decreased.

A schematic representation of the pedal-crank prototype (PP) tested in this study is shown in figure (11) (1: crank; 2: pedal). The length of crank arm (R), defined as the distance between the centre of the ‘‘bottom bracket’’ bearing and the centre of the pedal pivot, is normally fixed. However, on this prototype, the pedal pivot centre (3)/bottom bracket centre (4) distance changes continuously during the crank circumference. This is achieved by the use of a sun (6) and sun–wheel (5) gear type arrangement; the pedal pivot is attached to the ‘sun’ and rotates about the sun–wheel on roller bearings (7) to minimise pedalling resistance. In addition, the pedal and pivot are captive as one face of the enclosure (8) is open. Finally, the length of the pedal–crank system (distance 3–4) varies as a function of the crank angle.

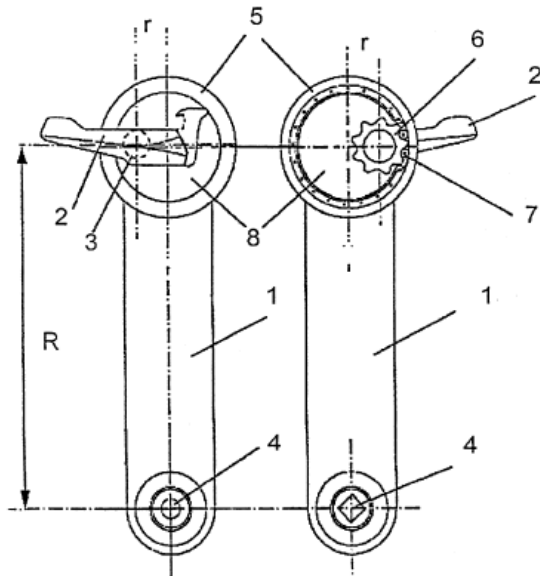


Figure 11: Schematic representation of pedal crank system adopted in this study (front view on the left, rear view on the right).

In the result of experiment, differences in radius and angular velocity between the two pedals are reported as a function of the crank angle. Even if the pedal–crank forces the motion of the lower limbs along a different path, the spanned angle changes accordingly, so that the angular speed during the crank revolution turned out to be almost the same as that of a standard, circular, pedal–crank system. Finally, to accelerate the limbs in respect to the body centre of mass (\dot{W} ; W), at a pedalling frequency of

60 rpm, amounted to 5.37W in PP and 6.57W in SP (e.g. an 18% difference between the two pedal–cranks). The improvements in the efficiency of cycling observed in this study were rather small (about 2%) and apparent only at the higher load tested. The result show that the transmission efficiency of cycling could be further improved by means of a pedal–crank of variable length.

2.7 Jeffery W. Rankin et al. [7] have performed a study with primary objective to determine if a non-circular chainring exists that improves cycling performance by increasing maximal power output relative to a conventional circular chainring during isokinetic pedaling. A conventional circular chainring provides a constant radius from the crank center to the chain driving the rear wheel, which provides a relatively constant crank angular velocity profile. In contrast, the radius of a non-circular chainring varies as a function of crank angle, and therefore alters the crank angular velocity profile over the pedaling cycle. The modified velocity profile alters the leg kinematics throughout the pedaling motion, and therefore has the potential to alter the contractile state of muscles (i.e., fiber length and velocity) and provide improved conditions for generating muscle power.

A detailed musculoskeletal model, forward dynamic simulation and dynamic optimization were used to determine the muscle excitation pattern and chainring shape that maximized average crank power over the pedaling cycle at pedaling rates of 60, 90 and 120 rpm. In order to provide a basis for comparison with the optimal non-circular chainring, a second optimization was performed at each pedaling rate using a conventional circular chainring in which only muscle excitation patterns were optimized.

The optimization successfully identified an elliptical chainring with an eccentricity (i.e., the ratio of major to minor axes lengths) of 1.29, which increased the average crank power by 3.0% at 90 rpm. See Figure (12).

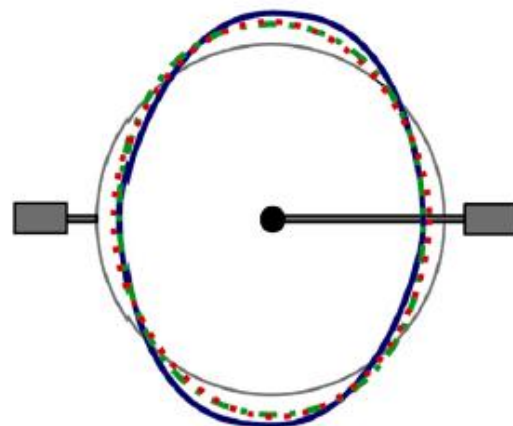


Figure 12: Optimal chainring shapes for each pedaling rate.

In figure (12) the solid, dashdot and dotted lines represent the optimal chainring shapes at 60, 90 and 120 rpm, respectively. The thin line corresponds to a circular 42-tooth chainring. The crank arm and pedals are shown in reference to the optimal orientation.

The major axis (corresponding to the center point of the slowest crank angular velocity) was rotated counterclockwise 91.81 relative to the crank arm. See figure (13). The optimizations at the lower and higher pedaling rates produced chainrings of similar shape to that obtained at 90 rpm, with eccentricities of 1.35 and 1.24 and major axis orientations counterclockwise from the crank arm of 84.91 and 91.91 for the 60 and 120 rpm rates, respectively. The average crank power also increased relative to the circular chainring by 2.9%

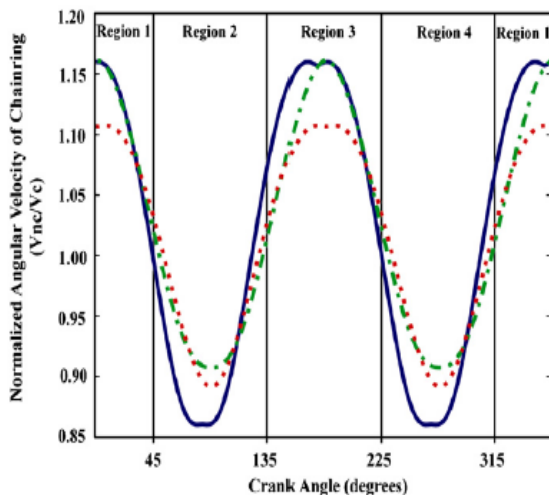


Figure 13: Optimal chainring velocity (V_{nc}) profiles normalized to the constant velocity of a circular chainring (V_c) over a single-pedaling cycle.

In figure (13) the solid, dash-dot and dotted lines represent the optimal chainring velocities at 60, 90 and 120 rpm, respectively. Crank angle is defined as 01 at top-dead-center and positive in the clockwise direction.

III. CONCLUSION

Different kinds of experimental studies have been performed by researchers related to driving mechanism of bicycle, tricycle or like vehicles. Many changes have been done in conventional drive mechanism in order to optimize operating performance. In some cases conventional sprocket-chain drive mechanism is replaced by new mechanism e.g. bevel gear & rotating shaft drive mechanism. An individual idea or any possible combination of different ideas can be used, in order to optimize operating performance of driving mechanism for cycle. The velocity ratio of mechanism, torque generated at drive side, pedal-

crank length, chain drive efficiency, chainring shape are some important parameters used to optimize performance of drive mechanism of cycle. Also the efficiency of the bicycle chain drive depends on the chain operation as it engages and departs from the sprockets on the high-tension part of the drive.

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