The Generation Four Bicycle

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Abstract

Per Pinkerton and Roberts, "A History of Rover Cycles", J. K. Starley claimed the real benefit of the safety bike was the ability to stand and pedal for supplemental power. The author has developed a recumbent bicycle that allows the seated rider to engage their upper body as when standing to pedal a conventional upright bicycle, thereby integrating the best attributes of conventional upright and recumbent bicycles.

If bicycles through history are organized by their means of propulsion, this configuration can be described as only the fourth fundamentally new bicycle configuration, after the Draisene, Boneshaker/Ordinary and current Upright/ Recumbents. It is not a perfect organization, but is useful. This is a Generation Four Bicycle, a “G4 Bike”.

This paper summarizes patent prior art, the development process, function, the current mature state of the G4 experimental prototypes, and their use. US patent 11,142,274, abstracted below, and a second patent application, “Recumbent Bicycle Providing Means for Supplemental Hand Power Input Analogous to Standing and Pedaling A Conventional Upright Bicycle” will also be addressed.

Introduction and Overview

This paper is a companion to, “The Generation Four Bicycle” presentation made to the International Cycle History Conference, held in Indianapolis, Indiana on 18 July 2022.

This paper and presentation provide information in a complimentary fashion and are intended for use together. As such, the 18 presentation charts and 16 back up charts are provided, in their entirety as the figures for this paper. They are provided at the conclusion of the text.

The text of this paper was developed by the author as part of two G4 Bike US patents. The first for the concentric crankset “Road Sport” variation (US 11,142,274). The second for the patent pending “Road Race” variant.

As overview, the balance of this paper consists of titles and abstracts for each patent. An extensive discussion or prior art and then a functional and physical summary of the Road Sport configuration is provided. The same is then provided for the Road Race variant. Finally, a brief summary and conclusion is provided. As the second patent was written with reference to the first, it is the authors hope and belief that the reader will find them reasonably integrated and concisely providing useful descriptions of the G4 and the history of bicycles from which the G4 Bike was developed.

Recumbent Bicycle and Methods of Riding Employing Supplemental Upper Body Power, Enhanced Aerodynamics, Stability, and Control

Disclosed is a recumbent bicycle configuration, structure and methods which allow effective hand power input using only components otherwise required to pedal and steer. Force and work based hand power methods are used. The effect is comparable to standing and pedaling a conventional bicycle. The configuration has front wheel drive and steering. The crankset is fork mounted on or near the steering axis. The fork has a double triangulated torque tube structure which is rigid from the hand grips to the crankshaft endpoints to torsional hand and foot forces in opposition. Pedal forces on steering are controlled by a hand over foot leverage ratio, and by use of trail, which is increasingly effective with speed. A fork mounted fairing can be used. For stability, the fairing aerodynamic center of presented area is ahead of the steering axis. Hand, foot and selective braking inputs are used for enhanced control.

Recumbent Bicycle With Power Input Analogous to Standing to Pedal an Upright Bicycle

Disclosed is a high performance recumbent bicycle that allows the rider to add substantial hand power by pulling the fork mounted crankset, about the steering axis, into foot pedal thrusts. The effect is superior to standing to pedal an upright bike, because the rider can provide power immediately, while remaining comfortably, safely and aerodynamically seated. Effective pedal force reaction is provided. Torque and work based hand power input methods are used. No supplemental mechanism is necessary. An embodiment has front wheel drive, a vertical steering axis, crankset offset ahead of the steering axis by a crankarm length, fork assembly rigid in torsion to rider hand and foot forces applied in opposition, and indirect steering mechanism which enables rider, grip, and pedal location and orientation for effective supplemental hand power input, and control of pedal forces on the steering. The enhanced steering control allows use of an aerodynamic disk front wheel.

G4 Road Sport Configuration Prior Art

The history of bicycle development shows there is an ongoing need for improvements which increase the power the rider can apply, particularly for acceleration and climbing hills, and which increase efficiency, speed, comfort, and safety. Better bikes could be used by more people for transportation, recreation, fitness and sport.

Baron Karl von Draise is generally credited with the first bicycle in 1817. It had a steerable front wheel for balance and directional control, a rear wheel, a seat and a connecting frame. The upright rider provided propulsion by pushing their feet directly against the ground.

The next generation fixed a crankshaft and pedals to the front wheel for improved propulsion. As lighter bicycles developed, wheel diameter was increased for higher speeds. To minimize the pedaling forces that were fed back to the rider and so that the wheel did not hit the riders legs when steering, the seat needed to be approximately in line with the steering axis and above the wheel. The high seat and pedal position was dangerous as the rider could easily be thrown forward and off the bicycle.

The conventional upright configuration, which is still in use today, emerged circa 1885. A roller chain and sprocket ratio was used to power the rear wheel. Rear Wheel Drive (RWD) separated the bicycle steering and propulsion functions thereby preventing any Pedal Force Feedback (PFF). The rider was in an improved position between wheels of a convenient and equal size. Importantly, this configuration also allowed the rider to safely stand on the pedals to accelerate and climb hills. These improvements resulted in a first, "Golden Age of Bicycles."

However, there are still fundamental problems with the basic upright bicycle configuration. The seat is still elevated, which can cause a dangerous fall and can be uncomfortable. The rider position is also poor aerodynamically which results in reduced efficiency and speed.

Commercial development of alternative bicycle concepts has been impeded by a Union Cycliste International (UCI) ruling in the 1930's. This sanctioning body prohibited the use of everything in official racing except the upright bicycle configuration. The ruling was apparently to emphasize human performance over bicycle technical innovation.

Recumbent bicycles nonetheless have been developed. The best alternative configurations can provide improved comfort, safety or aerodynamics. However, none allow the rider to stand and pedal to provide the additional upper body/hand power that can be generated on an upright bike.

Another inherent problem with the recumbent bike is interference between the pedals and the front wheel, as the natural position for both is low and forward. Attempts to resolve this conflict have resulted in Long Wheel Base (LWB), Short Wheel Base (SWB), and Compact Long Wheel Base (CLWB) configurations. The LWB puts the pedal crankshaft assembly behind what is usually a small front wheel. The resulting long wheelbase can cause poor low speed handling, be hard to transport and store, and can be heavy. The small front wheel results in increased rolling resistance, less ability to roll over obstacles, poor wear life, logistics and aesthetics. A SWB is achieved by locating the pedals above, rather than behind, a small front wheel. This configuration can be hard and dangerous to learn to ride because the elevated pedal position makes it difficult to put a foot on the ground when necessary. The CLWB uses two full size wheels, but the rider position problem is more severe because the pedals are higher yet. Additionally, these alternative configurations must transmit power the significant distance from the pedals to the rear wheel. This mechanism, which is usually a long chain with guides, is often heavy, greasy, dirty, claims space, and for efficient pedaling requires a bike frame structure which is heavy enough to resist chain line tension without significant flexing.

Front Wheel Drive (FWD) recumbent bicycles have also been developed. Alternative configurations have the pedal crankshaft assembly mounted either on the bicycle main frame or mounted on the fork. These mounting positions can be either inside or outside the front wheel perimeter. Mounting the crankshaft on the frame prevents PFF but complicates power delivery to the steerable front wheel. Configurations that mount the crankshaft on the fork are subject to PFF.

Mounting the crankshaft on the frame outside the front wheel perimeter is a configuration often used by current racing recumbents. Drive is typically by a chain that must twist as the front wheel is steered. This requires supplemental mechanism to guide the chain, limits the range of steering and the chain is prone to coming off the sprockets. Additionally, the crankshaft is usually mounted in a high position, over and ahead of what is often a small front wheel.

Mounting the crankshaft on the frame inside the front wheel perimeter is shown in the Debuit (US 2,505,464), Langen (US 6,419,254 B1) and Rutkowski patents (US 7,246,809 and 7,311,321 B2). The supplemental structure and mechanism required in this configuration adds complexity, weight, cost and limits the range of steering. It can also require excessive width between the pedal centerlines which can result in rider discomfort.

Mounting the crankshaft on the fork and outside the front wheel perimeter is shown in the Tolhurst patent (US 7,753,388). This bike has been commercially produced. It is known as a Moving Bottom Bracket (MBB) configuration. Here, importantly, PFF is reduced by the crankshaft offset which is the distance that the crankshaft is mounted ahead of the steering axis. The MBB configuration can be difficult to learn to ride because of the high crank position, the need to shift laterally as the crankshaft moves through the steering arc, particularly at low speed, and the need to control residual PFF.

When the crankshaft is mounted on the front fork and inside the front wheel perimeter it can also serve as the front axle. Examples of this "coaxial" or "concentric" configuration are shown by the Kretschmer patent (DE19736266A1) and in successive non-patent references by Kretschmer (Direct Drive (Chainless) Recumbent Bicycles, “Human Power” Issue 49, 1999-2000), Stegman (“Chain of Thought”, “Velo Vision”, December 2002), Garnet (US 9,139,254 B2, Velotegra.com/wordpress1 “Ergonomics of Direct Drive Recumbent Bicycles”) and Le Borgne (Kervelo, kervelo-bike.com, “Kickstarter Program April-May 2016).

Each of these examples strive to minimize PFF and they each do it a bit differently. Kretschmer aligns the steering axis toward the rider and uses a spring type fork centering system to mitigate resulting bike handling problems. Stegman, Garnet and Le Borgne each use crankshaft offset from the steering axis; Garnet maximizes that offset and also uses a spring to improve handling. Importantly, none show front fork structure able to resist significant torsional loads.

Notably, each also strongly advocated for use of a chainless front wheel hub transmission system of a sort described in the Non Patent References and in the Garnet Patent. Likely due to this focus, there are no reports that Kretschmer, Stegman or Garnet were able to build multispeed coaxial bicycle prototypes. It would be difficult to evolve and refine the basic coaxial bicycle configuration to a level of high performance without extensive developmental test and evaluation of successive prototypes equipped with some sort of effective multispeed transmission.

Le Borgne, most recently, was able to adapt a conventional bicycle bottom bracket transmission system into a front wheel hub configuration. However, that adaptation did not provide the gear ratios needed to pedal the bike at a high ground speed and its use of a single blade cantilever type front fork that did not adequately resist torsional pedal loads about the steering axis. Le Borgne also used a recumbent specific handlebar that lacked rigidity. Again, development of a high performance bicycle configuration could not be expected with these gearing and structure problems.

It is important to note that none of the fork assemblies disclosed by prior art were built with structure adequate to withstand the levels of torsion that must be transmitted for high performance methods of use. This is because the necessary bike configuration, structure, methods of use and the associated level of torsion produced are not at all obvious.

The prior art has also shown hand and foot powered recumbent bicycles of various configurations. The three patents by Thomas (US 3,910,599, 4,270,766, and 4,303,255) show coaxial FWD pedal recumbents that allow supplemental hand power application through a hand crank system. Thomas offset the hand and foot crank positions to minimize PFF. Problematically, the hand crank structure and mechanism adds weight, complexity and cost. It also appears to be difficult to hand crank, steer and otherwise control the bike. The effectiveness of this mechanism is further compromised because hand power is usually needed only intermittently, typically for acceleration and climbing, but the burden is continuous.

A variety of aerodynamic bicycle fairings are known. Kretschmer and Stegman both show front fork mounted fairings. They can allow more efficient and higher speed biking. However in windy conditions they can be unstable, hard to control and dangerous. Adequate guidance in the prior art on how a fork mounted bicycle fairing should be configured for stability in extreme windy conditions has not been found. Similarly, methods to effectively control that fairing while riding a coaxial FWD bicycle have not been found.

My invention resolves the deficiencies outlined above to provide a better bike which can be used by more people.

G4 Road Sport Configuration Summary

Disclosed is a recumbent bicycle that allows the seated rider to effectively apply upper body power, also called hand power, through the handlebars to supplement pedal input. The rider can use hand pressure to urge pivot of the crankshaft about the steering axis in coordinated opposition to pedal forces for an increase in torque applied to the crankshaft. The rider can also actually displace the crankshaft while simultaneously pedaling, which is an application of hand work. Both of which add hand power. Methods of riding include using only foot pedal input, adding supplemental hand force, and adding both hand force and displacement, or work input.

The bicycle configuration has front wheel drive, front wheel steering, and a fork mounted crankset. The crankshaft can be coaxial with the front wheel and the crankshaft centerline is on or near the steering axis. To efficiently apply hand power, the front fork assembly is rigid in torsion to the opposed forces of the riders hand and foot input. This rigidity extends from the handlebar grips to the crankshaft endpoints at which the crank arms are attached.

A key prior art objective has been to minimize or eliminate Pedal Force Feedback (PFF). Here, conversely, the pedal steering interaction mechanism for PFF is employed to allow supplemental hand propulsion.

The prior art uses crankshaft offset from the steering axis to reduce PFF. Here, it is not used because it also prevents hand power application. Instead, extended trail is used to manage PFF. Trail allows hand power input at lower bicycle ground speeds, where it is particularly important for acceleration and climbing, and increasingly controls PFF as the bicycle increases to cruising speed. Extended trail also allows stable and responsive handling of this FWD bicycle.

The embodiment can effectively use aerodynamic fairings. The front fairing is fork mounted. For stability the front fairing aerodynamic center of presented area is located ahead of the steering axis. The hand and foot inputs typical of riding this bicycle allow effective control of the faired bike. That control can be enhanced by a method of light braking while pedaling.

Seating is safe, comfortable and aerodynamic. The seat is at a safe chair-like height. The riders feet are reassuringly low and are forward to better prevent falling and protect the rider in case of a collision. This configuration makes the bike easy to start, to stop, and to learn to ride. The rider is more in than on the bike and is balanced between two full and equal size wheels. Riders vision is forward, up and at car eye level.

The result is a long sought capability comparable to standing to pedal a conventional upright bicycle while increasing rider safety, efficiency, comfort and aerodynamics. I believe this is a fresh, elegant and integrated solution to long standing problems that have previously been addressed with questionable success.

G4 Road Race Prior Art

The history of bicycle development shows there is an ongoing need for improvements which increase the power the rider can apply, particularly for acceleration and climbing hills, and which increase efficiency, speed, comfort, and safety. Better bikes could be used by more people for transportation, recreation, fitness and sport.

As described in the Applicant's prior patent, US 11,142,274, bicycle development began with the original Drasiene, patented in Germany in 1818, in which the rider pushed directly against the ground with their feet. A second generation of bicycle, which became popular later that century, added pedals to directly drive the front wheel. Early, heavy versions were known as "Boneshakers" and later, as they became more refined, as "Highwheelers." Late in the 1800's, the "Safety Bike" was developed and became very popular. This rear wheel drive configuration is fundamentally similar to most bicycles commonly available today. Although never as widely adopted, "Recumbent Bicycles" which seat the rider in a more horizontal position, were first seen shortly thereafter.

Bicycles through history can be classified, by their means of propulsion, into three distinct generations. The push powered Draisene was the first generation (G1). The pedaled, front wheel drive Boneshaker and High Wheel bicycles together formed a second generation (G2). The currently familiar, rear wheel drive bicycle forms the third generation (G3).

Additionally, as most recumbents have rear wheel drive, they can be classified as a subset of this third generation.

An important historical note is a public letter of 1885 by J. K. Starley, who was a prominent manufacturer of the G2 High Wheeler and was an early manufacturer of the G3 Safety Bike, which he called the “Rover”. As quoted in the book, “A History of Rover Bicycles” by Pinkerton and Roberts, page 36, Starley says:

> “The Rover is absolutely the outcome of a determination to obtain advantage previously unknown in a bicycle. We felt confident that a large percentage of unused power could be utilized if the rider were properly placed, particularly with regard to hill-climbing. In this we were not mistaken, as the enormous success of the Rover undoubtedly proves.”

Here, Starley asserts that the ability to stand and pedal the safety bike was the key reason for the popularity and commercial success of the G3 over the G2 configuration. Standing to pedal a High Wheeler was unsafe so not done.

Standing to pedal, for bursts of power, acceleration and climbing continue to be a major benefit of conventional upright bicycles. Although the best recumbents provide superior aerodynamic efficiency, speed, comfort and rider safety, they do not allow the benefit of standing to pedal.

G4 Road Race Summary

The embodiment resolves a longstanding deficiency of recumbent bicycles by allowing the seated rider to use a combination of both upper and lower body muscles to provide power. This is very much like when an upright bicycle rider stands to pedal.

Standing to pedal an upright bicycle allows the rider to add substantial, supplemental upper body or “hand” power. Standing first provides additional body weight required as reaction for increased foot pedal force. If the rider then forces the handlebars sideways, the bike and the attached foot pedal crankset both tilt. When the tilt is coordinated against a foot pedal stroke, the crankshaft endpoint moves against the attached crank arm, which creates torque that urges crankshaft rotation. This motion also changes the center point about which the crank arm is rotating, reducing the rider foot perimeter distance traveled, constituting hand work. As the rider continues to spin the pedals, this torque and work both contribute hand power.

Bicycle steering relies on both azimuth and roll control. Turning the front wheel about the steering axis changes azimuth, tilting the bicycle about the tire-to-ground contact points changes roll. As the upright rider uses bicycle roll to add hand power, the embodiment rider uses azimuth. The embodiments allow substantial hand power to be added by pulling the fork mounted crankset, about the steering axis, into the foot pedal thrust.

The longstanding need for recumbent bicycle supplemental hand power is demonstrated by an extensive body of USPTO prior art, which use supplemental mechanisms for hand power input. A problem is that the burden imposed by the mechanism is constant, but the utility is only intermittent. An important attribute of the embodiment is that it requires no mechanism for hand power input other than that used to steer and pedal.

The combination of hand and foot input, which is a process of pedal steering interaction, also results in enhanced steering control. This in turn allows routine use of an aerodynamic solid disk front wheel, even in blustery wind conditions.

The embodiment uses a leverage ratio to allow hand forces to control stronger foot forces. As with an upright, force on the handlebar grips is applied along a distance, to a fulcrum, and then along another distance to the foot pedal crankset. Configuring these distances and fulcrum provide the needed leverage. The embodiments use the steering axis as a fulcrum. For efficiency, rigid structure is provided along the lever arm distances. Front wheel drive and steering reduces these distances, thereby saving weight.

Use of indirect steering mechanism allows the rider, the hand grips and the foot pedals to be located and oriented so that hand and foot forces are applied most effectively, necessary force reactions are provided, and pedal force feedback is controlled. Hand or foot lateral displacement during hand power input is inefficient. To control hand grip lateral displacement, standoff is limited so that grips are aligned with their axis of rotation. To provide necessary reaction and to allow maximum force level input, hand and foot forces are applied in direct opposition. The vertical steering axis, a parallel handlebar axis of rotation, and perpendicular alignment of the riders foot pedal force input with the steering axis all facilitate hand and foot power input. A vertical steering axis also enhances embodiment low speed handling stability. Prior art teaches an inclined steering axis to control pedal force feedback.

Limiting the crankset displacement ahead of the steering axis also facilitates hand power input. An embodiment limits the crankset standoff distance to the length of the crankset crank arm. When pulling the crankset into the pedal thrust, the crank arm length offsets the crankset displacement. This is an effective balance that allows excellent hand power input and provides pedal force feedback control.

An embodiment also positions the rider seat height below the crankset height so that the peak phase of foot pedal force input is applied while the crank arm offsets the crankset displacement, which is the range of lowest pedal lateral offset. This maintains the leverage ratio for effective hand power input and pedal force feedback control.

The seat is readily adjustable for rider leg length and to vary the angle of recline. This allows a single frame size to fit most riders. The same bike can also be adjusted for a more relaxed upright rider position, or for a more aerodynamic highly reclined seatback angle. This adjustability teaches against FWD recumbent prior art which rigidly fixes the seat so as to better provide foot pedal force reaction.

These attributes are subject to trade as embodiments are configured for alternative applications.

Summary and Conclusion

The embodiments provide the best attributes of both upright and recumbent bicycles. Front wheel drive and steering allow the rider to be effectively integrated, to generate, and to efficiently apply hand and foot power, and to manage foot pedal force feedback. Since the rider does not have to stand, power can be applied immediately for bursts of acceleration and climbing. The embodiment also provides the aerodynamic efficiency, rider comfort and safety of the best recumbent bicycles. The embodiments provide balanced high performance and a new and satisfying ride experience. They are a fundamentally new type of bicycle, a Fourth Generation Bicycle.

Author Introduction

The author has been a professional engineer, department of defense weapon system analyst, and program manager, as well as a lifelong cyclist and craftsman. In 2014 he began full time design, development, fabrication, test and evaluation of what would become the "Generation Four Bicycle" - the G4 Bike. The G4 provides the aerodynamic efficiency, speed, comfort and safety of the best recumbent configurations, and lets the seated rider effectively engage their upper body as when standing to pedal a conventional upright bicycle. This allows excellent acceleration and climbing and an exceptional ride experience. The author and wife Peggy have enjoyed over 30,000 miles on G4 prototypes, they believe the configuration could be the future road bicycle.

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