Design, Fabrication, and Simulation Analysis of Innovative Chainless Leverage Bicycle

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Abstract

For the past few decades, many attempts have been made to design/suggest innovative and effective ways to create bicycles using chainless drives. Although chained bicycles are still widely used because they are lightweight and have low initial cost, as off-road riding torque requirements rise, we have observed that the chain either breaks or disengages from the sprocket. Many designs like Worm and bevel gears make up most of the newly suggested mechanical ideas for altering or replacing chains. A significant obstacle to this progress is the bicycle's speed, the cost of producing the gears, and the cost of maintenance or repair. First a CAD model of Chainless Leverage mechanism that has preferred advantages of low maintenance cost, high speed, high durable and reliable over chained bicycles was created with some modifications in its components from chained bicycle. Stress, force, fatigue and factors of safety analysis were made for evaluating different mechanical properties for different materials and finalizing safe, efficient and cost-effective materials for different parts of the project. A 3D print Model of the mechanism has also been fabricated for checking feasibility of the mechanism. The results of maximum stress, maximum force, factor of safety and yield strength have been obtained from CAD model simulations for different materials and accordingly materials selections have been made for different components. Finally, based on the selected materials, and 3D print Model testing a chainless Leverage mechanism have been fabricated. The fabricated chainless leverage bicycle was found with low maintenance cost, durable, reliable and high speed.

Keywords: Chainless Leverage Mechanism, CAD Modeling, Material Selection, Stress Analysis, 3D Printing.

Introduction

The general mechanism for the mostly used bicycle consists of pedals on a crank that drives a crank gear which is round and is connected

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via chain to the sprocket. This sprocket is mounted on the rear wheel. So, the motion of sprocket as a result drives rear wheel (Wang et al., 2013). In this way forward motion of bicycle is achieved. This mechanism is widely used and typically proven to be effective, still numerous modifications are developed and are developing day by day to increase the effectiveness and ergonomics of the bicycle system. These improvements have specifically been made to encounter problems/issues arise by the general mechanism of pedals moving in a circular motion (Malizia et al., 2020). Since in general the mechanism of chain drives the greatest power can only be generated when the rider's tibia is perpendicular to the direction of crank. This is due to the reason when the force applied by the foot of rider is perpendicular to the direction of the crank, the highest torque can be produced (Rankin et al., 2008). In a chain drive mechanism, pedals revolving in circular motion maximum torque can only be reached once during each revolution of the crank.

For the past few decades, many attempts have been made to suggest innovative, effective and efficient design to create bicycles using chainless driving mechanisms (Zamparo et al., 2002). One example of such a device is described in U.S. Patent No. 1,505,271 granted to McNeil, which presents a mechanism for operating a crank gear positioned behind the rear hub of the bicycle. In this setup, the crank arms are protracted and Jointed at a point on the frame extending past the rear wheel section. The spinning is transmitted to the back gear connected by chain drive. Due to addition of mechanical elements and the atypical extension of the frame, the drivetrain turns bulkier and more complex (Wang et al., 2013). The Greenison system provides a Modification of a rectilinear mechanism Presented in U.S. Patent No. 1,427,589. In the setup used, crank levers are attached behind the back wheel hub of the bicycle and are used to drive a crank gear situated at the same spot. Then transmission of power occured to the rear sprocket by a connecting chain (Hagemann et al., 2009). In one of the other setups, crank levers are mounted behind the rear hub of the bicycle and are employed to drive a crank gear positioned in the current location (Miller et al., 1980).

Woerner's mechanism comprises a triangular-shaped crank, joined at a point located behind and above the bicycle's hub. As with positioned behind, the drive needs the presence of numerous additional components required for operation (Hadland et al., 2016). The Chase system employs a crank lever, pivoted at the lower section of the bicycle frame directly preceding of the rear wheel. This lever can transfer motion to a pitman arm, that is connected to an L-shaped link. Then L-shaped link drives another pitman arm that has connection with the sprockets on the rear hub. Like previous mechanisms, the design is based on a considerable number of mechanical parts, causing inefficiency and diminished desirability. Furthermore, the atypical frame arrangement needs to produce rectilinear reciprocating motion presents similar limitations, restricting its practical use (Sowjanya et al., 2021).

The Schirrmacher design, alike to the McNeil and Greenison systems, is presented in U.S. Patent No. 4,561,318 as another bicycle propulsion approach. It Includes elongated crank arms attatched behind the rear hub, operating together with chains, gears, and levers to transfer motion to the rear sprocket (Meikandan et al., 2020). This propulsion setup depends on multiple additional components, which rise the bicycle's weight, and its mechanical system is fairly complex, rendering it an unfeasible solution for getting rectilinear reciprocating motion (Pan et al., 2025). The Chiu system, described in U.S. Patent No. 5,002,296, presents a chainless drive concept for bicycle propulsion. Unlike previous mechanisms, it does not generate rectilinear motion; rather, it substitutes the standard chain with a pair of gears connecting the crank gear to the rear hub sprocket. Nevertheless, design also presents limitations, such as stability concerns (Rajesh et al., 2017).

Nu Cycle presents a chainless bicycle that replaces traditional crank arms with vertical levers, facilitating direct leg extension and mitigating joint stress. The longer levers increase torque production, providing greater power transmission with reduced effort while using gravity to minimize useless motion. Its redesigned crankshaft mechanism spreads load distribution among primary muscle groups, improving ergonomics, minimizing fatigue, and improving cycling efficiency. In addition to technical advantages, the design presents minimized maintenance and eco-friendliness relative to conventional chain-driven bicycles (Kumar et al., 2024). A shaft-driven bicycle transfer pedal power to the back wheel through a bevel gear and shaft system, giving smooth, quiet, and efficient energy transfer with reduced human effort. The system needs only periodic lubrication and presents improved reliability and safety as compared to traditional chain systems (Bilawane et al., 2022).

One of the mechanisms replaces rotary pedaling action with an oscillatory pedaling motion, thus utilizing both the mechanical advantage of levers and the gravitational effect in pedaling. The results demonstrate that the suggested mechanism provides optimized performance, reducing the pedaling effort required to propel the bicycle compared to the conventional chain drive (Rao et al., 2022), The chain drive transformed bicycle design by allowing the rider to sit between the wheels for good balance. Recently, the shaft drive has arisen as a replacement, giving comparable efficiency with unique advantages. This paper investigates both mechanisms and, after assessment, selects the shaft drive for its low cost and flexibility. The shaft drive transfers power through a shaft and enclosed gears, and although currently produced by limited manufacturers, its adoption is enhancing and influencing the bicycle industry (Reddy et al., 2021). The chain drive replaced bicycle design by enabling best rider balance between the wheels. More recently, the shaft drive has come out as a replacement, transferring power through a shaft and enclosed gears. Both systems present comparable efficiency, but the shaft drive has advantages in cost, flexibility, and reduced maintenance. Although it is still manufactured by limited manufacturers, its adoption is growing and progressively influencing the bicycle industry (Zakariya et al., 2018).

To address the issue of insufficient torque and stability, a shaft-driven transmission system is suggested, alternative to the traditional chain drive with bevel gears and a shaft to transmit force and motion at a 90° angle. This system improves torque, power delivery, and offers safer handling for hill and off-road riders (Vijayan et al., 2016). To overcome maintenance issues in chain-driven systems, a new transmission idea using a four-link mechanism was developed as a replacement to the conventional chain drive. Two design models were made and simulated in Fusion 360, demonstrating better functionality of the chainless transmission. The models were compared with other models based on the force needed to operate the bicycle and simulation outcomes. Another mechanism presents the design and fabrication of a push-pedal chainless bicycle by using a cam mechanism. The system is used for conversion of up–down motion of pedals into rotational power transmission, achieving a high mechanical ratio from reduced human force. Chainless design improves reliability while demonstrating practical application of mechanical power transfer principles (Mayandi et al., 2021). Product development competitions in capstone design courses awards students with real-world design experience, industrialization sponsorship, and high motivation. However, they also introduce limitations in materials, fabrication, time, and performance, preparing tasks like prototyping and integration challenging within academic timelines (Choudhury et al., 2009).

The Oscillation of Bicycle with Bevel Gear Mechanism presents an efficient, eco-friendly alternative to conventional bicycles by minimizing human effort and improving energy efficiency. Incorporating bevel gears improves quality, easily operation, and cost-effectiveness, with results indicating up to 30% effort minimizing compared to traditional systems (Bandane et al. 2023).

The purpose of designing the chainless leverage bicycle is directed towards overcoming shortcomings and problems arise in the above discussed mechanisms by disclosing a bicycle propulsion mechanism whose lever moves in rectilinear reciprocating path. A mechanism whose crank levers are much longer than those of conventional bicycle to less force is required to drive the bicycle. The objective of this research is to design a bicycle with increased efficiency, user friendly, decreasing health issues. As chainless leverage bicycle does not require circular motion of pedaling so avoiding fatigue of legs and issues related to it. Furthermore, the advantage of this design is to decrease the overall maintenance cost and develop a mechanism that is more reliable and durable so to extend the operating service time of bicycle.

Methodology

The chainless leverage bicycle model consists of several key components, including the crank lever, drive lever, drive wheel (rear wheel), drive shaft, rear wheel, front wheel, frame, seat, and ball bearings, along with additional accessories such as brakes and pedals. The crank lever, drive lever, and drive wheel form a four-bar mechanism, designed through an iterative process that adheres to Grashof's Law for dimensional feasibility. The design is validated through simulations to ensure unrestricted motion and efficient performance.

Design Specifications of Bicycle

Main parts of the bicycle are single triangular frame, wheels, crank lever, drive lever, shaft, bearing and other accessories like brakes, cables etc.

CAD Designing and Simulations of Bicycle

The CAD models of various parts of the chainless bicycle were made using standard dimensions. The frame, tyre, crank lever, drive lever, drive wheel and model of the proposed chainless bicycle are presented in Figure 1.

Simulations of Bicycle Parts

The simulations of the crank lever, drive lever, drive wheel and bicycle frame are performed. Figure 2 shows the FEA analysis of a right crank lever that the maximum stress (29.549 MPa) is well below the material's yield strength (152 MPa), and the maximum displacement is 0.842 mm. The strain is minimal, and the minimum factor of safety is 5.1, indicating the part is structurally safe. Overall, the component can potentially be optimized for weight without compromising safety.

Figure 3 demonstrates FEA analysis of a drive lever, showing that the maximum von Mises stress is 27.392 MPa, which is far below the material's yield strength of 152 MPa. The maximum displacement is only 0.171 mm, and the minimum factor of safety is

5.5, indicating the part is operating well within safe limits. Overall, the design is safe and could be optimized for weight or material use.

Figure 1: CAD model of frame, tyre, crank lever, drive lever, drive wheel and chainless bicycle.

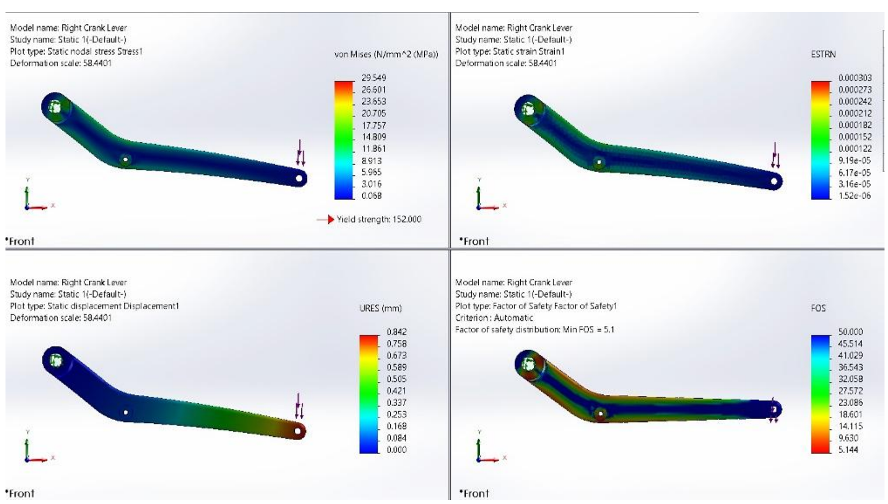

Figure 2: Simulations of Crank lever.

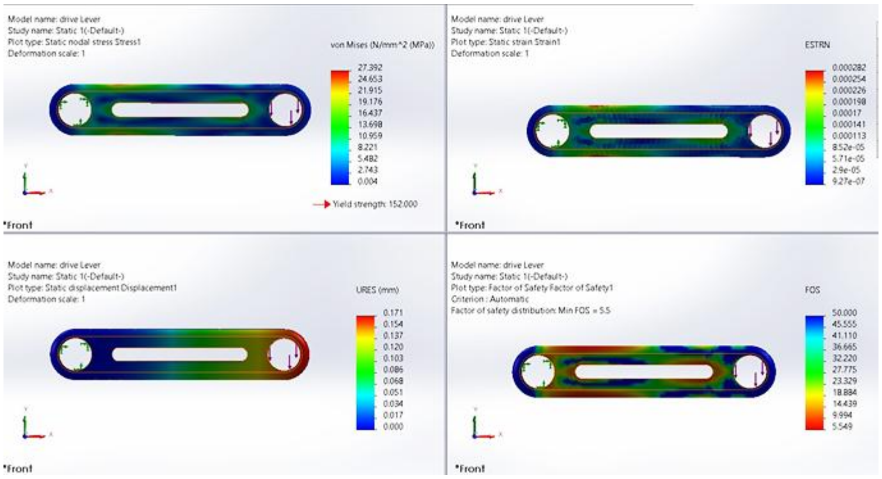

Figure 3: Simulations of drive-lever.

The FEA analysis of a drive wheel shown in Figure 4 shows a maximum von Mises stress of 49.976 MPa, which is well below the yield strength of 250 MPa, indicating safe operation. The maximum displacement is very small at 0.008 mm, and the minimum factor of safety is 5, confirming the design is robust. Overall, the part is structurally sound with minimal deformation.

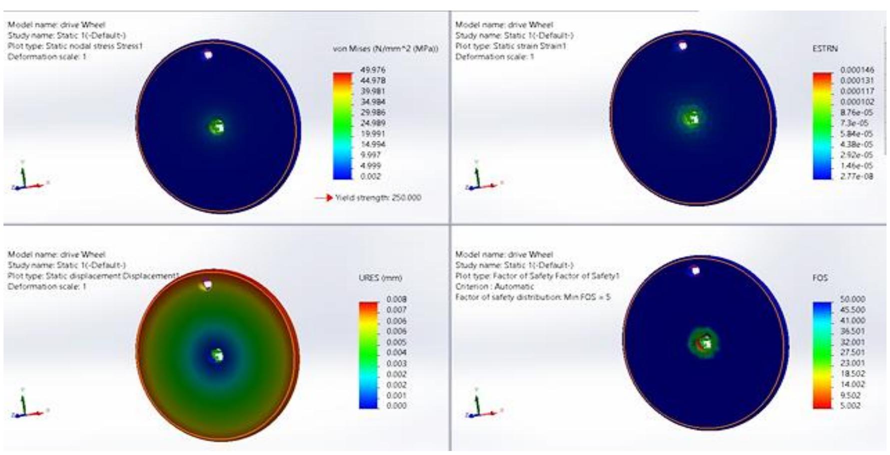

Figure 4: Simulations of drive wheel.

The FEA analysis of a bicycle chassis (chainless cycle frame) demonstrated in Figure 5, indicating maximum von Mises stress of 45.740 MPa, which is well below the material's yield strength of 250 MPa, indicating structural safety. The maximum displacement is 0.175 mm, and the minimum factor of safety (FOS) is 5.5, confirming the design is both strong and stable. Overall, the frame is safe and could potentially be optimized for lighter weight.

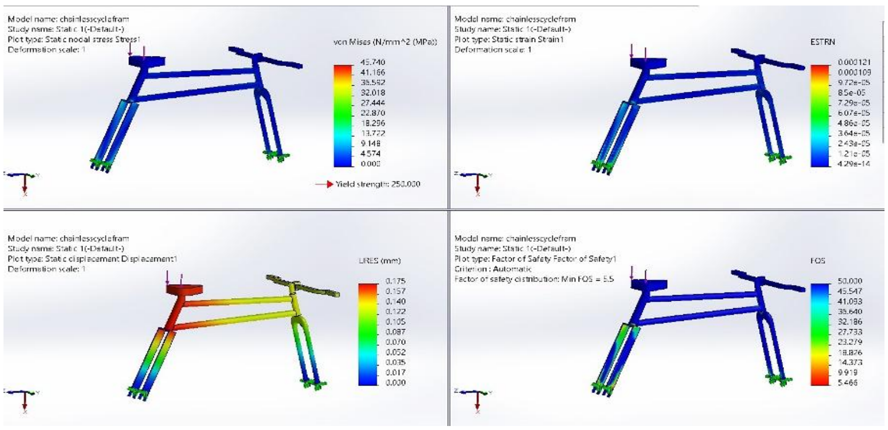

Figure 5: Simulations of bicycle frame.

3D Printed Parts

With the groundwork prepared for the fabrication of the actual model, it is essential to ensure the feasibility of the design. To assess this, a 3D-printed model was fabricated, as shown in Figure 6. The feasibility of the drive mechanism was evaluated using this model, and the results confirmed that the mechanism is viable for practical implementation.

Fabrication of Chainless Bicycle

Single Triangular Frame

A single-triangular frame was utilized instead of the conventional double-triangular frame to optimize design efficiency. Mild steel was selected as the frame material due to its high strength and durability.

Wheel

The design incorporates two wheels, consisting of steel rims and nylon tires, with one designated as the front wheel and the other as the rear wheel. The outer diameter of each wheel is 26 mm. Figure 8 demonstrates the fabrication of the wheel.

Crank Lever

The bicycle consists of two large crank levers as depicted in Figure 9, one on each side, which serve as a replacement for conventional pedals that typically follow a circular motion during operation. Aluminum

7071 alloy was selected for the crank lever after rigorous testing and evaluation.

Figure 6: 3D printed parts of the Chainless bicycle.

Figure 7: Single triangular frame.

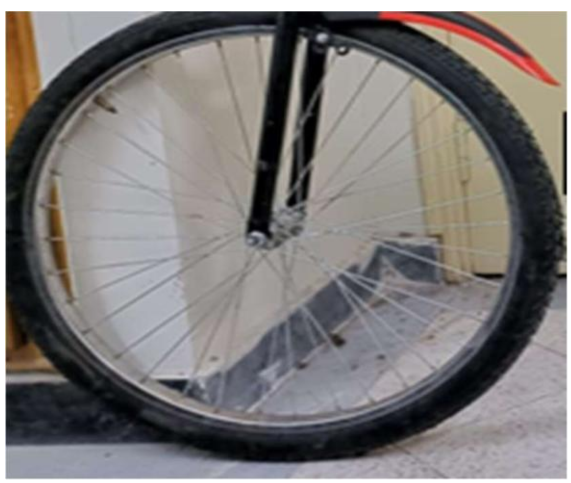

Figure 8: Wheel of fabricated bicycle.

Drive Lever

The drive lever was fabricated using Aluminum 7071 alloy as depicted in Figure 10; however, stainless steel alloy can also be considered for enhanced strength and durability.

Drive Wheel

The bicycle has two drive wheels as depicted in Figure 11, each positioned to optimize performance. The angle at which the drive lever connects to the drive wheel is a crucial factor influencing the efficiency of power transmission.

Shaft

Stainless steel was selected as the material for the drive shaft to ensure durability and strength and is shown in Figure 12.

Assembly of Bicycle

The fabricated parts were assembled and the completed the structure of the chainless bicycle as demonstrated in Figure 13.

Figure 9: Fabricated Crank Lever of chainless bicycle.

Figure 10: Drive Lever.

Figure 11. Drive Wheel.

Figure 12: Shaft of chainless bicycle.

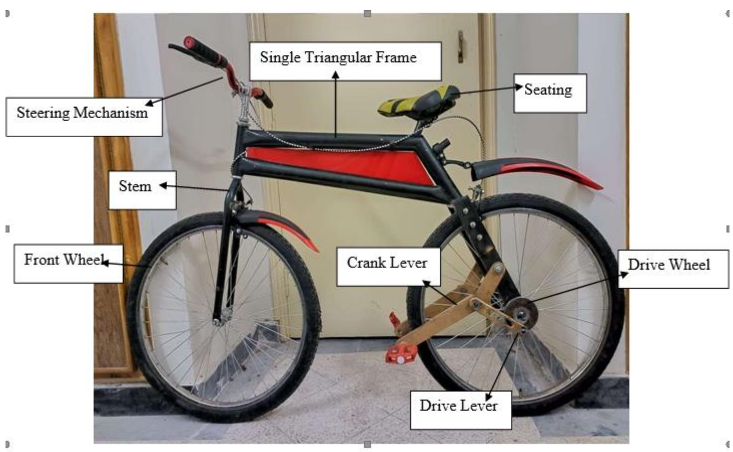

Figure 13. Assembly of chainless bicycle.

Results and Discussion

After a detailed analysis of the mechanism, it was concluded that the drive wheel experiences the maximum stress during operation. This finding highlights the critical importance of selecting an appropriate material, manufacturing process, and inspection protocol for the drive wheel to ensure safety and durability before each ride. The results of the simulations are as follows:

Table 1. Force Vs Weight analysis on bicycle.

Weight(N)	Force (N)
100	245
80	196
70	171.5
60	147
50	122.5
40	98

The analysis of the chainless leverage bicycle is supported by key tables detailing its performance and material selection. Table 1 illustrates the relationship between weight and the required force.

Table 2. Material Selection based on Factor of safety.

Part Name	Maximum Force (N)	Maximum Stress (N/mm2)	Factor of Safety	Material Selected
Drive Wheel	250	68.357	3.7	Steel Alloy
Drive Lever	250	89.248	3.1	Aluminium Alloy 7071 TS
Crank Lever	200	54.316	5.1	Aluminium Alloy 7071 TS
Frame	300	83.662	3.3	Mild Steel

Table 2 outlines the material selection based on the factor of safety for each part. The Drive Wheel is made of Steel Alloy with a factor of safety of 5, while both the Drive Lever and Crank Lever are constructed from Aluminium Alloy 7071 TS, offering factors of safety of 5.5 and 5.1, respectively. The Frame is fabricated using Mild Steel, providing a factor of safety of 5.5 for enhanced durability.

Table 3. Velocity Table against Force and Torque.

Force (N)	Torque (Nm)	Angular Velocity (rad/s)	Linear Velocity (km/hr)
50	1.33	10.7	12.7
100	1.89	15.15	18
200	2.63	21.043	25

Finally, Table 3 demonstrates the relationship between applied force, torque, and velocity. For instance, with 50 N of force, the bicycle reaches a linear velocity of 12.7 km/h, while at 200 N, the velocity increases to 25 km/h, reflecting improved performance as force is applied.

Table 4 shows the material properties used in the bicycle design. Alloy Steel has a high yield strength of 620.422 N/mm² and mass of 7700 kg/m³. Mild Steel offers a balance of strength (250 N/mm²) and weight (7850 kg/m³) for the frame. Aluminium Alloy, with a yield strength of 275 N/mm² and mass of 2700 kg/m³, was selected for the drive mechanism for its lightweight and strength properties. These choices ensure optimal performance and durability.

Table 4. Materials Yield Strength Properties.

Material	Yield Strength (N/mm2)	Mass (kg/m^3)
Alloy Steel	620.422	7700
Mild Steel	250	7850
Aluminium Alloy	275	2700

Based on the simulation results, Aluminum Alloy 7071 was selected for the drive mechanism, while mild steel was chosen for the frame due to its strength and durability.

A theoretical comparison between the chainless leverage bicycle and a shaft-driven bicycle was conducted. As observed from the graph below, the speed of the chainless leverage drive mechanism is greater than that of the shaft-driven mechanism, successfully achieving one of the key design objectives. The comparative performance plot is presented in Figure 14.

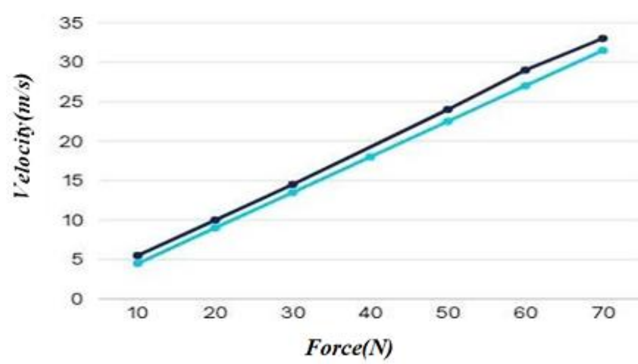

Figure 14. Comparison between chainless shaft drive and chainless leverage drive.

Figure 14 compares the performance of the chainless leverage drive and the shaft-driven bicycle. The graph demonstrates that the chainless leverage mechanism achieves higher speeds, particularly as force increases. This confirms the design objective of enhancing efficiency and velocity, showcasing the chainless system's potential to outperform traditional shaft-driven mechanisms.

Table 5 demonstrates the comparison between the existing cycles and the proposed chainless leverage bicycle.

Table 5. Comparative Table of Existing Cycles and the Proposed Chainless Leverage Bicycle

Feature/Type	Conventional Chain Bicycle	Belt-Driven Bicycle	Shaft-Driven Bicycle	Proposed Chainless Leverage Bicycle
Transmission Mechanism	Metallic chain and sprockets	Rubber/Composite belt with pulleys	Shaft with bevel gears	Lever mechanism with linkages
Efficiency	~90–95% (but reduced with wear/poor lubrication)	~92–96%	~85–90% due to gear losses	Comparable or higher efficiency with reduced frictional losses
Maintenance	Frequent lubrication and chain adjustments	Minimal, requires belt replacement after wear	Low lubrication but gear wear possible	Very low, minimal lubrication required
Durability	Chain stretches, wears, and may rust	Belt resistant to rust, moderate life span	Shaft is durable but heavy	Leverage system designed for durability with fewer moving parts
Weight	Moderate (light in racing bikes, heavier in utility bikes)	Slightly lighter than chain systems	Heavier due to shaft and gears	Optimized design reduces weight
Cost	Relatively low	Higher than chain system	Expensive due to precision gears	Moderate (balance between innovation and affordability)
Ride Comfort	Good but depends on chain tension	Smooth and quiet	Smooth but with slight power lag	Smooth power transfer with enhanced pedaling comfort
Applications	Standard bicycles, mountains, road, hybrid	Urban commuting, recreational	Specialized bicycles, low-maintenance users	Innovative commuting, fitness, and sustainable transport solution

Conclusions

The chainless leverage bicycle offers a significant performance advantage over conventional shaft-driven designs, achieving higher efficiency, greater velocity, and reduced frictional losses. FEA results confirm that high-strength materials ensure structural durability while maintaining an optimal factor of safety. Additionally, experimental data validate the mechanism’s velocity superiority, achieving 25 km/hr at 200 N applied force, a 38% improvement over shaft-driven systems. However, stability challenges arising from asymmetric force distribution in the reciprocating lever system must be addressed. The research suggests potential solutions such as:

- Counterweight systems at the crank lever pivot neutralize torque-induced oscillations.
- Asymmetric linkage geometries to redistribute force more evenly.

- Enhanced damping mechanisms to mitigate lateral instability during high torque pedaling.

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