Review on various design aspects of the modern bicycle

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Abstract. In today’s world where we are surrounded by the smoke emitting vehicles, we must come up with more effective and sustainable solutions for transport. One of which is electric vehicles and other being bicycle. Since the innovation of bicycles till date a lot of improvements are done in its design, utility, and applications. Bicycle riding is one earliest modes of transport. Being so, it is the cleanest way of transportation as does not create any waste out of it. Bicycle riding is also considered as one the most effective ways of exercising. Bicycles find the largest market in the vehicle industry as it attracts small kids right from the age of 4 yrs to senior citizen. The advancement in the field of ergonomics plays vital role in doing so. The developments on design and power transmissions have also up lifted the bar for utility. Due to this the application of bicycles now is not limited to simple exercising, racing, or travelling but also in the field of adventure sports, mountain climbing etc. Keywords: Material frames, transmission system, electric bicycle, spokeless and center-less wheel

1. Introduction

As we all know our mother earth is facing the biggest issue of its lifetime which global warming and unfortunately the reason for that is humanity. The continues emission of harmful pollutants like carbon-monoxide, carbon-dioxide, greenhouse gases and the unburnt hydrocarbons are affecting our ecosystem with an untraceable pace. So, in this era of such advanced technology, we should focus on coming up with sustainable solutions for the existing pollution causing technologies. To make a small start, we can concentrate on our transportation system and work on it. Many developments have been done in designing bicycles which makes its usability greater than ever.

This review paper is a sincere effort to club the modern-day advancements in field of designing bicycle and its aspects. It covers all the topics involved in the design of a modern-day bicycle right from design considerations for frame, materials, alternative transmission systems, design of e-bike and its considerations along with calculations involved in component selections and finally including recent advancement in the wheel design. While compiling this review paper we have studied many papers to the understand the selection criteria for the material of bicycle for different applications and the basic framework for different bikes. We also studied different transmission systems like shaft driven, gear driven, transmission on the idea of treadmill and electrically assisted bicycles. The point of attraction in new age bicycles is the spokeless and the centreless wheeled bicycles. It brings major effect ergonomically in modern day bicycles. The advancements also help to increase market appeal for such bicycles. The spokeless wheel not only increases ergonomic aspect but also increases durability and usability.
2. Design of Bicycle frames & Material Selection.

Designing of the frame of a vehicle is the most important aspect of the designing process. Here we'll referring two papers [1][2]. In [1][3] structural analysis and optimization is considered whereas [2] talks about tresses and deflections developed in the frame.

Chien-Cheng Lin et al describes structural designing as, the geometry of bicycle defines properties and performance of it and riders' comfort and behaviour depends upon length and angle of frame. For proper analysis the frame they have used CAE and numerical method to calculate forces and tresses acting upon it. They describe structural analysis as mainly two parts intensity and life evaluation of structure and other is structural optimisation. To analysis a particular system it is very important to understand the loading points of the system. Hence, they have described the weight of the rider acting upon the frame in different situations like stand still, braking, turning, Turning and braking as shown in Figure 1.

By keeping this in mind they have undergone multiple optimisations and iterations and the research states that most rigid frame type is the diamond-type frame, then there is triangular frame, then the parallel frame with larger pipe centre distance, and finally, the parallel frame with smaller pipe centre distance, which has the least rigidity. After a lot of iterations, they have also found out the optimum material which should be used as per the requirement and application of bicycle. [1]

![Figure 1](image)

**Figure 1.** Analysis of the effect of: [a] external forces on a turning, [b] external forces on a braking, [c] external forces on the weight of a braking and turning, and [d] inertia and friction forces on the weight of a braking and turning bicycle. [1]

P. D. Soden et al, to calculate the tresses and deflections generated all the possible conditions are considered be it rider in stand still position or rider going uphill or downhill etc. and they have compared the theoretically calculated tresses and deflections to the practically obtained results. The maximum stresses at the starting and severe braking are generally too high. At the time of starting, maximum stress is 60 per cent of the $\sigma_t$ and more than 50 per cent of the $\sigma_t$. Also, they say that failure due to fatigue, of certain components, if has to be calculated an extensive data will be required which gives the information about actual force exerted and frequency of occurrence. Also, lateral bending which is due to the forces offset from the plane leads to maximum stresses in the skeleton. [2]

CorneliuRontescu et al describe material selection as one of the major issues of designing of bicycle frame. It must be verified, whether the material is suitable and can stand stress, load. Simulation of bike frame was done. In their study[4] they have considered 3 material which are Al alloy, Ti alloy. Materials used have wide range of application. There is no material that has only advantages, so several materials were used. They advise to have seamless tubes for the frame which
can be obtained by rolling or extrusion. Assembly of bike is carried out by WIG. For experimental research 3 types of materials were taken, and it was found that alpha beta titanium alloy is optimum material for the application, but due to its high cost it finds difficulties in mass utility. [4]

M. A. Maleque et al in their paper[5] they explain the contribution of material selection. Material stages includes mathematical model, general material performance requirement, initial screening of material and optimum material selection. In mathematical model stress acting on frame are shown. More strength allows less material to be used. Material selection chart shows easy visualisation. Material with low cost is preferable. Digital logic method can be used for selection. Performance index shows capability of material. Material selection CUP and digital logic method were used. Their study shows that Kevlar Fibre-epoxy Reinforced Plastic is the most suitable material for the purpose. [5]

3. Designing of alternate mechanical transmission system for bicycles.

There are many attempts made by various people all over the world to find an effective and more reliable transmission systems for bicycle some of them are Shaft Driven, Bevel Gear driven, Internal Gear Driven and many more.

The attempt to design shaft driven bicycle [6][7][8], replaces the traditional chain sprocket arrangement with a set a bevel gears and a shaft connecting them. This requires basic gear designing calculations, shaft designing and its calculations along with the knowledge of material selection for the gear and shaft. After designing the required components their CAE analysis is done via different CAE software like Ansys. It is very imp to check whether the stresses developed in the gear teeth and the shaft are well under the limits described by Equivalent von Mises stress.

![Figure 2. Components used and Assembled view of gear and shaft transmission system.](8)

Drawbacks stated with the shaft driven are unwanted vibrations generated at high speed, gear backless which leads to noise generation and heating of gear. Solutions provided in [6], they have analysed have problems and have found out the causes of it, if gear slipping occurs at rear gear it is mostly due to excessive load on peddle which can be removed by aligning gears and providing lubrication, if noise is generated it is due to insufficient lubrication, if jamming of gear is caused it is due to accumulation of unwanted particles in the gear system which should be rectified by providing casing to the gear box, also vibrations can lead to misalignment of PCD.

The attempt to design Bicycle with internal gear transmission is provided in[9]. The components they have used to do so are pivoted peddle with internal gear and spur gear connected to the wheel hub assembly. They have described this mode of transmission as the easiest way of transmitting human effort into mechanical output which can be generated in either standing or sitting passion. By using simple calculations, they have evaluated number of rotations of wheel that can be generated with chain as power transmitting unit and internal gear system as a power transmitting system and they have reached to a conclusion that by using internal gear system additional of 1.5 rotations of wheel are achieved to that of chain driven system.
Shivan Singh et al, came up with an innovating way to power the bicycle with the help of mechanism like that of treadmill, instead of peddles rotating a shaft with a pair of gear. Working of this mechanism include the rider who walks on a conveyor belt connected to the shaft driving the wheel with the help of chain and sprocket. It requires simple torque calculation that is need to overcome the static friction which is to be provided by the rider. [10]

Prof. Dr. Geramitcosky et al, have effectively explained designing of gears for the shaft driven transmission system, the main areas of interest are shape, size, terminology, analysis of force, stress and durability of the gear. At the time of calculations, it is very important to find out the maximum limit of the gear to transmit torque before reaching failure. Major ways of failure are Pitting, Scoring, and breakage. To calculate bending stress, endurance and durability certain necessary assumptions are also listed. Furthermore, using C++, they have developed a programme to calculate the strength of the gear and is not to be used for designing. [11]

Yi-Chang Wu et al have gave 3 basic gear option to the rider through their paper [12]. The 3 modes are low-speed gear, direct-drive gear and high-speed gear. The low-speed gear the speed ratio is high and hence gives an easier pedalling experience to the rider. The direct drive gear has a speed ratio of 1 and the high-speed gear has the speed ratio the least. In the traditional 3 speed rear transmission which uses planetary gear mechanisms have higher mechanical components, high contact which created faster wear and high maintenance and expensive gear tooth profiles. By introducing the magnetic gear mechanism all these problems have been given solutions. With all the above said, calculations have also been done to show that this is practically viable and diagrams have been included as well. [12]

Paolo Baldissera et al have mainly focused on the difference between the power transmission of Rear wheel drive and Front wheel drive. Currently all the competitive market producers use front wheel drive to tackle the disadvantages of rear wheel drive which includes lower efficiency. But with this solution [13] comes to major design challenges which are a potential decrease in transmission efficiency and difficulty in placing the gear shift mechanisms. To tackle this an electromechanical actuation of a moving cassette shifter was developed. [13]

4. Design of Electric Bike.
This section explains the design considerations considered while designing EB. Different power trains and framework needed for EB is explained.

Shweta Mate et al, have described electric bike which runs on battery with charging. Solar panel can also be included. Electric energy which is stored in DC battery is converted. Working [14] medium is sulphuric acid. Calculations were done for selection of different components. Advantages are low maintenance, easy to carry, less energy consumed, high efficiency. Drawbacks are High centre of gravity, environment changes. Energy efficient and cheaper.[14]

Srinivas Mutyal in his paper has described main effect of e-bike as to overcome pollution. Frame is made from MS. Frame is designed to sustain weight of person recent motorbike consists of single
cradle frame. He has used BLDC motor [15] which has advantages like reliability, high starting torque. Technical specifications were compared. Controller is used to control electric system. Some components in his design are BLDC motor, PIC Controller, Battery. Electric bike id designed, and calculations are made. Comfortable and efficient design can be achieved. [15]

Vignesh M. et al have come up with optimum design of frame for e-bike. Objective of paper [16] was to design and fabricate light weight frame. Scope of research was design of e-bike which will be light weight and sturdy. They have described a methodology showing flowchart of processes taking place. Several factors are included in data collection, length, weight, height was considered. Material selection was done as per the study and UNS G41300 was selected. Selection of rake angle is crucial part; it determines type of vehicle. A base line is drawn to initiate design of frame for mounting. It also includes construction. Additional significance is considered for selection of bend angle, Swing arm was connected to chassis, Swing arm acts as major platform. After designing of frame assembly was performed. Calculations were made. Analysis was done which includes impact test, torsional test, harmonic analysis. In Impact test amount of impact material can absorb can be determined. Torsional test is done to prevent torsional fatigue failure. Analysis proves to be safe. Various material like carbon fibre and titanium can be used. [16]

Although the world is moving towards E vehicles, in Italy hydrogen-fuel cell-operated bicycles are still used. Antonella Petrillo in their paper discuss about an electric pedal-assisted bike and a hydrogen fuel cell operated bike is compared to see the performances in form of efficiency and impact on environment. This includes [17] the phases of Production and usage. In the production phase, the e-bike leads with all the parameters, i.e., the e-bike is less impactful to the environment. This is because of the complex production and materials required in H-bike. In the usage phase, the H-bike leads, except a couple of parameters. Analysing both the phases we deduced that e-bike is the most sustainable option we have. [17]

![Figure 4](image)

**Figure 4.** Mechanical transmission between the motor shaft and the pedal shaft. [18].

C. Abagnalea et al in this paper talk [18] about a new model of power-assisted bicycle instead of a direct power transmission. This model is the ped-elec prototype. In this model, the motor is kept in the central positions by a bevel gear through which it transmits the torque on the central hub. This is different from the usual models which has the motor on one of the 3 hubs. This paper focused on getting better test trials. This model helped them achieve reduced tracking errors and good robustness. [18]

Since we now know that electrically assisted bicycles have taken the market, the study by Jean-Marc Timmermans et al tells us a comparison among different models available in the market[19]. By looking at the table we can say that the speed is more or less the same for all the bikes. It comes to the personal choice of the customer what he prefers.
| TOP SPEED (km/h) | Compensation at starting | Compensation on flat | Compensation at slope |
|------------------|---------------------------|----------------------|-----------------------|
| Sample 1         | 25                        | NA                   | Good                  |
| Sample 2         | 25                        | V. Good              | V. Good               |
| Sample 3         | 25                        | Medium               | Medium                |
| Sample 4         | 25                        | NA                   | Good                  |
| Sample 5         | 28                        | V. Good              | V. Good               |
| Sample 6         | 20                        | NA                   | Medium                |
| Sample 7         | 20                        | NA                   | Good                  |
| Sample 8         | 28                        | NA                   | Good                  |
| Sample 9         | 22                        | NA                   | V. Good               |
| Sample 10        | 28                        | NA                   | V. Good               |
| Sample 11        | 30                        | NA                   | Good                  |
| Sample 12        | 25                        | V. Good              | V. Good               |

5. Electric Motor and Its Calculations.

There have been quite a few choices regarding the motors to be used in an electric bicycle. A couple of them being a DC motor with chain, a BLDC motor without chain and BLDC motor with chain.

T. Porselvi et al, have done an extensive study for designing selection criteria of electric motor which are used to replaces IC engine in an Electric vehicle. Procedure of proper selection of rating of electric motor is described in their paper [20]. Vehicle dynamics is considered for selection electric motor. Power rating vehicle dynamics like rolling resistance, gradient resistance, aerodynamic drag also must be considered. Types of motors used in electric vehicles are DC series motor, 3 phase induction motor, permanent magnet motor. Motor is designed using ANSYS Maxwell software. Simulation output and parameters meets necessary characteristics required for driving. [20]

Saurabh Chauhan in his paper [21] has explained a method for calculating power required for e-vehicles. Motors are available with number of variations. Factors affecting torque are rolling resistance, grade resistance, acceleration force. Rolling resistance depends on co-efficient of rolling friction which varies depending upon material of tyre and roughness of surface. Grade resistance is the force that tends to pull the vehicle back when it is climbing an inclined surface. Acceleration force is the force that helps vehicle to reach predefined speed from rest in a specified period. Required torque has been calculated it is necessary to check if wheels of vehicle are capable enough to transmit the required amount of torque. [21]

Additionally, Sunikshita Katoch et al in their paper talk about the combination of a BLDC motor and chain drive. The advantage here is that it gives a better way to change gears in the bike. It is simpler and more reliable than the other 2 options cited in the other papers.[22]

6. Design of Spokeless and Centreless Wheel.

With advancement in technology there came the need to have innovative wheel designs to accommodate different types of transmission systems which include spokeless and centreless wheels. Such wheels also contribute majorly in ergonomic aspects to increase the market appeal for bicycles.

S. Vinoth Kumar et al, Describes the innovation in wheel design which helps absorbing shocks and damps the vibration in wheel itself. The basic work of spoke is to in tension and provide proper stiffness and rigidity to the wheel, the authors propose to replace the spokes of wheel with the metal strips acting like leaf springs, which would provide cushioning effect at the time of riding. They have performed analysis of the both the wheel i.e with and without spokes to justify their design. Results shows it increases the load bearing capacity of the wheel as a whole.[23]
Shubham Bankar in his paper has used the same basics of leaf spring to minimize the shock, increase comfort and ride quality the only difference is the mounting hub and the metal strips. Here the author suggests arranging three metallic strips in elliptical shape between a triangular hub and the rim to provide the cushioning to the wheel. The comparison between [23] and [24] can’t be certainly done as [24] does not show analysis results and maximum load carrying capacity of the wheel. [24]

S. Mohindar et al, have come up with an innovative idea of lunatic bike while eliminating its hub. They describe having large wheels provide comfort ride as small wheels are light. Stability of large wheels is great as of small wheels. Power developed from pedal is transmitted to gear mounted on main shaft. Transmission of power is developed and is used in two-wheeler applications. Advantageed includes, it is more efficient, replaces chain drive, compact, increase torque. Drawbacks [25] includes suspension system not included belt may damage. Power transmission is more as compared to other. [25]

![Figure 5. Photograph of Lunatic Hub-less wheel.](image)

Tushar B. Pokharkar et al, came up with similar for motor vehicles using RLS, here they are transmitting motion from bearing to wheel. In this design [26] amount of material production cost is minimized and use of spoke is eliminated. Experimental results show decrease weight it makes the bike lighter. Vibration is reduced. Elimination of spokes increase safety and provides stability.

Mr. Manoneet Kumar in his paper [27] talks about the new concept of having no Hub and the spokes in a wheel. This is done to reduce the restricted motion on the wheels. This in turn reduces the mechanical components which in turn reduce cost and the weight of the vehicle. A brief description and methodology for manufacturing is explained by him in this paper. [27]

![Figure 6. Exploded view of hub-less wheel.](image)
In addition to the earlier paper commented above [27], this paper [28] studies 3 types of hub-less wheels and talks about best among the three. Practical experiments suggested various parameters that were checked and these parameters are yet to be researched and work upon according to the paper. In addition to already established advantage of decreased weight, this paper establishes the advantage of better accuracy in steering due to the higher resistance given during tilt by reducing the angle allowance by the bearings. Because of removal of hubs and spokes, the centre of gravity is lowered which gives better riding experience and comfort. Braking leverage is also improved in this case. Along with the advantages, a few demerits have also been talked about including difficult manufacturing and assembly. A few calculations have been performed and diagrams have been mentioned.

7. Conclusion
This paper is an effort to review and summarise modern day bicycle developments related research papers and literature. We have tried to cover all the basic aspects of designing on fabricating bicycles. Work of different authors and publishers is compiled, studied, and compared to have complete knowledge in the field of designing bicycles. This paper also touches the aspects of ergonomics of bicycles which plays important role in sustaining the product in market. Day in and day out we see new technologies coming into the market, people have found place for those in bicycles and have come up innovative designs.

The compilation helps new people trying to design and fabricate innovative bicycles and launching them into the market by giving an overview on all aspects of design. We have also covered selection criteria suggested by various authors in the field of materials, frame types, gears for transmission system, electric motors and controllers, and different wheel designs.

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