Design and Development of Effortless Bicycle

R G Dhamak[1], Prof. P N Nagare[2] and Prof. A K Mishra[3]

***Abstract*—A motorcycle uses fossil fuel to propel which is depleting and also polluting the environment. Trips within the range of 15km to 20km or more can be easily covered with the help of human muscular power and these vehicles are also available at cheaper rates compared to motorbikes. As the fitness perspective of a human being is concerned pedaling is the best exercise which an individual should do. But the problem faced in doing so is the efforts required to ride the vehicle, which totally exhaust us. So to overcome the problem a single slider crank mechanism with Neodymium magnets (NdFeB) on one side of the slider and spring on the other side can be incorporated in the existing model of a bicycle which will directly assist the force applied by the rider and increase it in specified amount. This can be achieved by using magnetic repulsion force to move the piston from TDC to BDC, the repulsive force pushes the slider in the cylinder and a spring fastened at the bottom of the cylinder helps the slider to move it from its BDC to TDC. After some time when the bicycle tends to slowdown again the crank can be paddled to over the resistances occurred due to wind, rolling and gradient if any. Instead of mounting an electric motor to assist the rider in hilly areas and making the bike complicated and expensive, mechanism can be incorporated to perform similar function. It will be a revolution in automobile sector that people uses bicycle (or their muscular power i.e. human powered vehicle) for their daily transportation. Similar innovative ways can also be used in four wheeled vehicles, instead of sitting idle in the car; we can also be the part of producing the energy rather just being a consumer of it.**

***Index Terms*—Muscular Power, Pedaling, Slider Crank Mechanism, Neodymium Iron Boron (NdFeB) Magnets, Repulsive Force, Human Powered Vehicle (HPV)**

I. INTRODUCTION

THE purpose of this project is to design a bicycle which can run faster compared to conventional bicycles with less pedaling force to drive it. So to obtain the speed of 40 to 50 km/hr with minimum efforts of the rider can be achieved with the help of various techniques such as by using an electric motor to assist the pedaling force or by reducing aerodynamic drag force or by increasing the size of rear sprocket or the length of the crank (pedals) can also be increased. So the development in green vehicles [1] is today's major concern, among them light electric vehicles such as electric bicycles are very effective. Recently electrical bicycles are more popular which assist the rider and make him comfortable to drive in hilly areas. In this E-Bike or Pedelec (**Ped**al **Ele**ctric **C**ycle) an electric motor is used to drive crank set in bicycles. These are one of the most commonly used forms of transportation in the world, mostly used for short distance trips. The production had climbed to over 100 million per year (compared to 50 million cars) twice as many as automobiles. Much of the world uses bicycles as a primary form of daily transportation. Instead of walking for several hours to cover a specified distance, it becomes faster and more efficient on two wheels. Reaching speeds of 30 km/hr is achievable by even a beginner. The exercise benefits of cycling are well known.

Cycles are being kept aside because of the efforts required to ride it and also because of rider's social reputation. Lot of research is being going on to increase the speed of bicycle by keeping its pedaling force constant. Keeping the input force constant and increasing the speed by using some alternative means such as adding additional gears or substituting electric motors or by incorporating mechanism which can assist the pedal force.

This paper is dedicated to develop a human assisted bicycle with a slider crank mechanism operated on magnetic repulsion and spring force to oscillate into the guide, which is assembled on the rear wheel to assist the pedaling force. The ultimate objective of this bike is to attain 40-50 km/hr speed which will make it more preferable vehicle for short distance trips.

II. LITERATURE REVIEW

The first step in the invention of this glorious machine can be tracked down in 1791 at Parisian Park a toy-like machine named Hobby Horse as a plaything for rich. Improvement in it is seen in 1817, now front wheel can be turned by a handle. This was named as Draisienne after German Baron von Draise or a Velocifer. The first treadle led true bicycle appeared in 1830 which was ridden with both feet's entirely off the ground by a Scottish blacksmith named Krikpatrik MacMillan. In 1863 Pedals were added to the front wheel. The Bone-shaker is launched. Riding velocipedes soon becomes a fad [1].

In 1865 Radial (and torsion) spokes are introduced making bicycles lighter. Solid rubber tires are introduced replacing iron tires. Then the term 'bicycle' was first used in 1869. In 1870 Tangential spokes are used replacing radial and torsion spokes. No major change since then. J K Starley

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invents the Rover safety bicycle in the year 1888. In 1889 Pneumatic tires were first used. The development of the basic bicycle is complete. In 1896 Coaster brakes invented. Then in 1899 mile-a-minute barrier broken, Murphy completed a mile in 57, 75 second. In 1903 bicycle mechanics Orville and Wilbur Wright invented the Aeroplane. Then in 1965 conservation movement and physical fitness buffs recognize the importance of bicycle and a bicycle boom begins. In 1972 for the first time ever, bicycles outsell cars in United States of America. Disc wheels were introduced in 1980 for competition bicycles to reduce the aerodynamics drags due to individual spokes. John Howard in 1985 sets the speed record at 152.28 mph.

R. S. Jadoun et al**.** [3**]** in their paper they discussed the flaws in the conventional electric bicycle which was propelled only with the battery power and no human muscular power can be assisted to it. In their work they designed the bicycle which can run on both electrical as well as pedal power. With the aid of battery it can travel for 2 hours at a speed of 15km/hr and the battery can again be charged within 1 hour. Frederic Grappe et al. [4] in this the importance of air resistance is discussed and also how it can be calculated if the frontal area, density and velocity of air, total mass and coefficient of air drag is known. Paper is having different methods to calculate drag force which in turn provide possible ways to reduce it. T. S. Olds et al. [5] in it is based on equating two expressions for the total amount of work performed. One expression is of biomechanical principle and other is from aerobic and anaerobic energy system. It predicts performance, physiological requirements effects on performance and other unknown or un-measurable characteristics. James C. Martin et al. [6] in this cycling power is determined accurately and model for it is prepared. It is compared with a power measurement system for validating. Now a day's SRM power measurement system is very common. Carmelina Abagnale et al. [7] in the journal it discussed about the model for electric motor assisted bicycle. So that the human power can be modeled separately with motor power and in the last the total power required can also be determined.

III. Problem Definition And Objectives

A. Problem Definition

Conventional cycling requires more driving force which is cumbersome for the rider that leads to inefficient working of the cycle. At present the amount of output torque obtained by the drive train is incompetent to cope up with the speed requirement of the rider.

For this purpose a magnetic repulsive force can be used to assist the pedaling force which will directly increase the speed of the bike.

B. Objectives

The main objective of carrying out this project is listed below:

1. Mathematical modeling of the bicycle.
2. Power calculation of conventional bicycle..
3. Selection of magnet for proposed slider crank mechanism. .

IV. Magnet Selection

1. Ferrites Commonly known as Ceramics, have been in production since the 1950's. They are primarily made from Iron Oxide (FeO) and the addition of Sr and Ba through a calcining process. They are the least expensive and most common of all magnet materials. Primary grades are C1, C5 and C8. They are mostly used in motors and sensors.

2. Alnico These are one of the oldest commercially available magnets and have been developed from earlier versions of magnetic steels. Primary composition is Al, Ni and Co, hence the name. Although they have a high remanent induction, they have relatively low magnetic values because of their easy of demagnetization. However, they are resistant to heat and have good mechanical features. Common applications are in measuring instruments and high temperature processes such as holding devices in heat treat furnaces.

3. Samarium Cobalt They belong to the rare earth family because of the Sm and Co elements in their composition. Magnetic properties are high and they have very good temperature characteristics. They are also more expensive than the other magnet materials. They come mostly in two grades: SmCo5 and Sm2Co17, also known as SmCo 1:5 and 2:17. Common uses are in aerospace, military and medical industries.

4. Neodymium Also known as Neo, these are the strongest and most controversial magnets. They are in the rare earth family because of the Nd, B, Dy, Ga elements in their composition. A relatively new group of commercial magnets, they are controversial because they are the only magnets that have been patented for both composition and processing. The patent and licensing issues are important and will be discussed later in this guide.

5. Bonded Magnets All of the above materials are available as bonded grades by extrusion, compression, calendaring or injection molding processes. The magnetic properties are lower because they sometimes lose their anisotropy and they are not fully dense due to the introduction of resins and epoxies. The main advantage to this group is that they can be made in complex shapes and can be inserting, over-molded and co-molded with other materials.

Neodymium magnets are a member of the Rear Earth magnet family and are the most powerful permanent magnets in the world. They are also referred to as NdFeB magnets, NIB, because they are composed mainly of Neodymium (Nd), Iron (Fe) and Boron (B). They are a relatively new invention and have only recently become affordable for everyday use.

B. Grades of Neodymium

N35, N38, N42, N38SH...what does it all mean? Neodymium magnets are all graded by the material they are made of. As a very general rule, the higher the grade (the number following the 'N'), the stronger the magnet. The highest grade of neodymium magnet currently available is N52. Any letter following the grade refers to the temperature rating of the magnet. If there are no letters following the grade, then the magnet is standard temperature neodymium. The temperature ratings are standard (no designation) - M - H - SH - UH - EH.

Table No. 1
Grades of Neodymium Magnet

Grade of material	Max. working temperature	Br		Hcb		Hcj		(BH)max	
		mT	KG	KOe	KA/m	KOe	KA/m	KJ/m3	MGOe
N35	80	1170-1210	11.7-12.1	⩾10.8	⩾860	⩾12	⩾955	263-287	33-36
N38	80	1210-1250	12.1-12.5	⩾10.8	⩾860	⩾12	⩾955	287-310	36-39
N40	80	1250-1280	12.5-12.8	⩾11.6	⩾923	⩾12	⩾955	302-326	38-41
N42	80	1280-1320	12.8-13.2	⩾11.6	⩾923	⩾12	⩾955	318-342	40-43
N45	80	1320-1380	13.2-13.8	⩾11.0	⩾876	⩾12	⩾955	342-366	43-46
N48	80	1380-1420	13.8-14.2	⩾10.5	⩾835	⩾12	⩾955	366-390	46-49
N50	80	1380-1450	13.8-14.5	⩾10.5	⩾835	⩾12	⩾955	374-406	47-51

1. Residual Induction (Br) (or flux density**)**, is the magnetic induction corresponding to zero magnetizing force in a magnetic material after saturation in a closed circuit; measured in gauss.

2. Coercive force of a material (Hcb) of a material is equal to the demagnetizing force required to reduce residual induction, Br to zero in a magnetic field after magnetizing to saturation, measured in oersteds.

3. Intrinsic coercive force of a material (Hci) indicates its resistance to demagnetization. It is equal to the demagnetizing force which reduces the intrinsic induction, Bi, in the material to zero after magnetizing to saturation; measured in oersteds.

4. Maximum energy product (BH)max is the maximum product of (BdHd) which can be obtained on the demagnetization curve.

C. N42 50mm X 15mm

According to the design of the mechanism N42 is suitable both economically and technically. The dimensions are again finalized on the basis of its location; thickness of the magnet is directly proportional to its MGOe, more the thickness of the magnet more will be its repulsion force.

V. BICYCLE MATHEMATICAL MODEL

Traditionally, torque, speed and power needed to meet the travel range are the basics in vehicle design. Cost of ownership and maintainability are some of the factors. Lately, environmental impacts have also been considered in a sustainable design approach. Torque that is required to drive the bike is based on wind drag, gravitational force and rolling resistance. Aerodynamic drag is proportional to the product of the frontal area (A) and drag coefficient Cd []. Rolling resistance occurs due to continuing deformation of tires, which is proportional to tire flexibility and surfaces in contact. A less elastic and more flexible tire creates higher rolling friction []. Normal components of the weight (vehicle, rider and luggage) contribute to rolling resistance. The power requirement to propel the bike is given as in [6]:

$$P = 0.5\, \rho\, Cd\, A\, v^3 + mg(Crr \cos\theta + \sin\theta)v \qquad (1)$$

where, P is power (Watt), ρ is air density (1.29 kg/m^3), Cd is drag coefficient, A is effective frontal area in m^2, θ is slope of the road, mg is weight, v is velocity of the bike and Crr is coefficient of rolling resistance. As shown in Eq. (1), power depends up on area, velocity, weight and slope of the road.

A. Bicycle Terminology

Power is a measure of how much energy is being changed every second. For cyclists, the effort they put into pedaling either makes them go faster or helps them fight against drag and rolling resistance. Some important terms used in analytical cycling model are as follows:

*1. Wind Resistance (F_w)***:** It is the force in Newton's on the rider and bike caused by wind drag. Variables affecting drag are effective Frontal Area of bike and rider (A), Drag Coefficient (C_w), Air Density (ρ), and Speed (V).

2. Rolling Resistance (F_{rr}): It is the force in newtons on the rider and bike caused by the rolling friction on the road. Variables affecting rolling resistance are the coefficient of Rolling Resistance (C_{rr}) and the Weight of the rider and bike (W).

3. Gravity Forces (F_g): It is the pull experienced by the rider on bike when bike is moving down the slope. The slope of a hill is defined as rise divided by horizontal run. This is expressed as a decimal number.

4. Power (P): It is the work required per unit of time to overcome the net forces acting on the rider and bike.

5. Speed of the Pedal (V_p): It depends on the cadence (C_d) and the crank length (C_l).

6. Average force on the Pedals (F_{av}): It is during a revolution is related to power and the speed of the pedal, (V_p).

7. Effective Pedaling Force (F_{eff}): It gives the force in each of two legs that is required to give the same average force (F_{av}), while pedaling in only a portion, *Eff*, of a full rotation of the pedals.

8. Air Density: It is the mass of air in kilograms per cubic meter.

9. Cadence (C_d): Revolutions per minute of the pedals.

10. Coefficient of Rolling Resistance (C_{rr}): Dimensionless parameter describing the retarding force of rolling divided by the weight of a rider.

11. Coefficient of Wheel Drag (C_{wd}): Dimensionless parameter describing the drag on a wheel as speed and wheel diameter varies.

*12. Coefficient of Wind Resistance (C_w)***:** Dimensionless parameter describing the retarding force exerted by the air as a rider moves.

B. Torque and Power

Torque is dependent on the length of the radial arm and a tangential force (Ft) [4]. During pedaling, the angle between the tangential force and the radial arm varies: force application is constant and vertical in the upright seating position but the direction of the arm is changing in a circle as shown in Fig.2

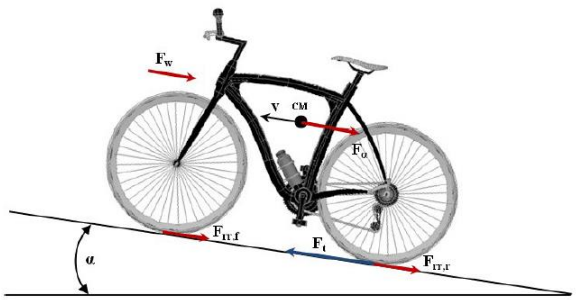

Fig: No. 1

Longitudinal components of forces acting on the Bicycle

The average torque (τ) is determined as in [6]:

$$\tau = \frac{1}{\pi}\int_0^{\pi} rF\sin\theta\,d\theta = \frac{2}{\pi} rF = 0.64rF \qquad (2)$$

The crank-arm length is constant but the application of force on the paddle depends upon the types of seating positions. Upright seating with a 180 mm crank length with a 9.43 rad/s as a non-professional cyclist speed is used for best performance. Transmission ration between the peddling (cog wheel) and rear-wheel decides the power of pedaling and the speed of the bike.

With a pedaling cadence of 9.43rad/s, lever arm of 0.178m,cogwheel radius (r_{cp}) of 75mm, rare sprocket radius (r_{cw}) of 40m and wheel radius of 305mm as shown in Fig. , the transmission ratio will be 0.533.

The transmission ratio of almost half suggests that the angular velocity of the wheel is half the angular velocity of the paddle. In electric motors, the angle between force and the lever arm vector stays constant. The bike is designed for a maximum velocity of 13.4m/s. Power on the wheel is based on the amount of the torque required to maintain the ride and the angular speed as shown in Eq. (3).

$$P = \tau\omega \qquad (3)$$

A drag coefficient of 1.2 is used considering the larger width and lower seating position on the bike in comparison to a common bicycle. A bike speed of 13.4m/s is used as a reference believing such speed is needed in order to make an o table difference in comparison to other modes of transportation.

The drag force of 78.6 N computed at a speed of 13.4 m/s. Normal force is determined by the weight of the bike (84.3 kg) and rider (137 kg). For a recommended tire pressure of 2.76 bar and velocity of 13.4m/s, the rolling resistance coefficient (C_{rr}) is 0.00962, and the resulting rolling resistance force is 20.9 N. Drag and the rolling resistance forces ums to a total resistance force (F_{total}) of 99.5N, which is the driving force needed to ride the Trike at a speed of 13.4m/s on a flat plane. For pedaling at the speed of 5.39 m/s, drag and rolling resistance forces are computed to be 12.7 N and 18 N, respectively. For a pedal lever arm of 0.178m, torque at the pedal τ pedal is 3.7 Nm, and with the wheel lever arm of 0.305m, torque at the wheel τ wheel is 30.3 Nm. Powers for paddle and motor driven are shown in Fig. 4. As shown in Fig. 4, the power requirements increase with the velocity of the Trike. The power to reach a speed of 13.4m/s is 1,330 W (1.78hp) and the power needed for manual peddling at a speed of 5.39 m/s is 65.8W [7].

VI. Conclusion

Mathematical modeling of the bicycle is done and power required for driving the bicycle is calculated. The magnet is selected on the basis of power requirement and high MGOe (Mega Gauss Oersted) i.e. magnetic field. N42 is best suited on the basis of its repulsive force for proposed slider crank mechanism.

Appendix

A. Sample Calculation of Power

The raw data recorded for each test are shown below. These data, in conjunction with the model parameters (i.e., coefficient of rolling resistance, drag area, bearing friction and drive chain efficiency), were used to calculate the estimated power for each trail as shown below:

Raider mass	80 kg
Bicycle mass	10 kg
Wind direction	310^0
Wind Velocity	2.94 m/s
Time to cover 471.8 m	56.42 s
Initial velocity	8.28 m/s
Final velocity	8.45 m/s
Ride direction	340
Grade	0.003

B. Calculated Values

Ground velocity $V_G = \frac{471.8m}{56.42s} = 8.36$ m/s

Air velocity $V_{WTAN} = 2.94$ m/s $\cos(340 – 310) = 2.55$ m/s

$V_a = V_G + V_{WTAN} = 8.36 + 2.55 = 10.91$ m/s

Yaw angle $V_{WNOR} = 2.94$ m/s $\sin(340 - 310) = 1.47$ m/s

$$\text{Yaw} = \tan^{-1}\left(\frac{1.47}{10.91}\right) = 7.7^0$$

Drag area based on yaw angle. For this subject, drag area at 5 and 10^0 was 0.258 and 0.257, respectively. Interpolation to a yaw angle of 7.7^0 yields the corrected drag area.

$$C_DA = [(0.257 - 0.258)/(10 - 5)](7.7- 5) + 0.257 = 0.2565$$

Aerodynamic power:

$$P_{AT} = V_a^2 V_G 1/2 \rho (C_DA + F_w)$$
$$= 10.91^2 \times 8.36 \times 0.5 \times 1.2234 \times (0.2565 + 0.0044)$$
$$= 158.8 \text{ W}$$

Rolling resistance power:

$$P_{RR} = V_G \cos[\tan^{-1}(G_R)]C_{RR}\, m_T\, g$$
$$= 8.36 \times \cos[\tan^{-1}(0.003) \times 0.0032 \times 90 \times 9.81$$
$$= 23.6 \text{ W}$$

Wheel bearing friction power:

$$P_{WB} = V_G (91 + 8.7\, V_G)10^{-3}$$
$$= 8.36 \times (91 + 8.7 \times 8.36)10^{-3}$$
$$= 1.4 \text{ W}$$

Power related to changes in potential energy:

$$P_{PE} = V_G\, m_T\, g \sin [\tan^{-1}(G_R)]$$
$$= 8.36 \times 90 \times 9.81 \times \sin [\tan^{-1}(0.003)]$$
$$= 22.1 \text{ W}$$

Power related to changes in kinetic energy:

$$P_{KE} = 1/2\, (m_T + I/r^2) \times (V_{Gf}^2 - V_{Gi}^2)/(t_i - t_f)$$
$$= 1/2 \times (90 + 0.41/0.311^2) \times (8.45^2 – 8.28^2)/56.42$$
$$= 2.3 \text{ W}$$

Net power:

$$P_{NET} = 158.8 + 23.6 + 1.4 + 22.1 + 2.3$$
$$= 208.2 \text{ W}$$

Total power:

$$P_{TOT} = P_{NET}/E_C$$
$$= 208.2/0.976 = 213.3 \text{ W}$$

For this bout the SRM power averaged 218 W.

C. Nomenclature

V_G = Ground velocity (m/s)
V_{WTAN} = Tangent component of wind velocity (m/s)
V_a = Air velocity (m/s)
V_{WNOR} = Normal component of wind velocity (m/s)
C_D = Coefficient of air drag
A = Frontal area (m^2)
P_{AT} = Aerodynamic power (W)
F_w = Factor associated with the wheel rotation
P_{RR} = Rolling resistance power (W)
G_R = Rode gradient (rise/run)
C_{RR} = Coefficient of rolling resistance
m_T = Total mass of bike and rider (kg)
g = acceleration due to gravity (9.81m/s^2)
P_{WB} = Wheel bearing friction power (W)
P_{PE} = Power related to changes in potential energy (W)
P_{KE} = Power related to changes in kinetic energy (W)
I = moment of inertia of the two wheels (0.14 kg · m^2)
r = Outside radius of the tire (m)
V_{Gf} =Final ground velocity (m/s)
V_{Gi} = Initial ground velocity (m/s)
t_i = Initial time (s)
t_f = Final time (s)
P_{NET} = Net power (W)
P_{TOT} = Total power (W)
E_C = Chain efficiency factor

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