International Journal of Engineering Trends and Technology
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I11P203

Volume 69 Issue 11, 15-21, November, 2021

Original Article

Development of Amphi-Elliptical Bicycle

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Abstract - *The sole purpose of putting forth an idea for developing a cycle with elliptical pedaling is to subconsciously attract the customers towards buying a workout bicycle, thereby laterally promoting the usage of non-polluting vehicles for shorter distances. The concept of elliptical pedaling is nothing but combining the slider-crank mechanism along with the normal bicycle. The ease of operating an elliptical bicycle when compared with a normal bicycle makes it to be represented as a standout product. Although conceptually the idea is already available, one additional attribute in this proposed product differentiates it from other elliptical bicycles, i.e., making the elliptical bicycle float in water. By adding detachable floating supports on the sides of the elliptical bicycle, it is possible to make it float in flood-prone areas. Combining these two ideas is a completely new concept resulting in the name Amphi-elliptical bicycle since it can be used both on land and water. Establishing this type of vehicle at a considerably low cost with the attributes mentioned above will emerge it as a successful product in the market because people are turning to be more health-conscious and are trying to act responsibly to contribute in some way for reducing pollution in the environment. This product will even be available at tourist attractions replacing normal bicycles shortly as it acts as an entertainment vehicle.*

Keywords — *elliptical pedaling, workout, non-polluting, slider-crank mechanism, floating supports, Amphi-elliptical bicycle, low cost*

I. INTRODUCTION

The idea behind choosing to work on a modified bicycle is the outcome of an alarming increase of fuel-based vehicles, which causes enormous pollution to the environment. On average, at least there are two motorbikes and one car per family, which has become an essential part of living and has also become a status symbol. People are ready to invest in a comfortable vehicle by applying for loans and repaying them every month. Over a period, people are starting to realize the ill effects of urbanization and are trying to contribute to the environment by participating in social activities, including saplings planting. When an entire norm was skipped from BS4 to BS6, it was evident that each citizen was responsible for the contamination of the environment somehow. But at the same time, vehicles have become an integral part of our lives. So, the only way people can reduce pollution is by using cycles to relatively shorter distances. Introducing a regular bicycle would be monotonous and normal. Therefore, the concept of elliptical pedaling in bicycles would attract a much huger population towards it. This elliptical bicycle ensures a regular exercise routine along with controlling pollution by replacing motorbikes for shorter distances. One additional attribute that will attract the people is making it float in water using tubes of truck tires. This enables the bicycle to float in flood-prone areas making it an efficient amphibious cycle. The mechanism involved in an elliptical bicycle will be technically explained in forthcoming pages, although for an easier understanding, it is nothing but converting the normal trekking movement of a person into pedaling motion which turns to be a good cardio exercise.

A. Elliptical Bicycle

The normal movement of running or walking is converted into rotary motion by means of introducing elliptical pedals replacing the normal pedals. In a normal cycle, motion is achieved by rotating pedals directly attached to the chain and sprocket arrangement. Therefore, one complete revolution of the pedal is achieved to recover an efficient motion of the cycle. In the case of elliptical pedaling, the footrest of the pedals is recessed to the bearing, which rolls over a lengthy rod that is at a comfortable inclination. The back end of the footrest is fastened with a nut and washer to a crank axle that links with the chainring of the chain and sprocket arrangement. Therefore, when the footrest rolls over the rod, the pedaling becomes easier because, for one forward and backward rolling of the footrest over the rod, an entire revolution of the pedaling is completed by means of the crank axle.

B. Float Attachment

Making the bicycle float has become an essential part of the happening times because people can construct houses in the rain flood-prone areas. Typical fuel-based vehicles cannot withstand the water in flooded regions. Therefore, there is no means to ride such vehicles in the water. But this defect can be overcome by using floating attachments on either side of the bicycle. Initially, it was planned to add PVC pipes attached to the elliptical bicycle through foldable holders. But due to budget constraints, a different idea was adopted. Instead of using PVC pipes, it was planned to install two truck tyre tubes of 1m diameter on either side of the elliptical bicycle. It was found to be relatively cheap. The tubes were wrapped with a flat metal bar with bolt holes and inflated to the desired level not more than 80 psi pressure. The inflated tubes were attached to the elliptical cycle by means of a hollow rod along with which the tube holders were bolted using 12 mm bolts. Double purpose includes the exercising module as well as the floating characteristic offered by the bicycle.

II. DESIGN CALCULATIONS

A. Connecting rod calculations

Let us consider the connecting rod to be supported beams with one end hinged and another with roller support. The footrest is placed exactly at the center of the connecting rod, wherein the point load will act. The point load is nothing but the self-weight of the person cycling.

Length of the rod, l = 1.016m

Diameter of the rod, d = 0.02 m

Point load, P = 120kg = 120*9.81=1177.2 N=1.177kN
AC = CB = 0.508m

Reactions at support,

$R_B + R_A = 1.177kN$ --------------- (1)

Moment about A,

$R_B * 1.016 = 1.177 * 0.508$

$R_B = 0.5885kN$

$R_A = 1.177 – R_B$ ------------------ from (1)

RA = 0.5885kN

***a) Shear force diagram*:** To find Shear force,

Shear Force at B, $F_B = -R_B = -0.5885kN$

Shear Force at C, F_C = 1.177-0.5885kN = 0.5885kN

Shear Force at A, F_A = 0kN

b) Bending moment diagram: Find Bending moment,

Bending Moment at B, M_B = 0 kNm

Bending Moment at C, M_C= (W*l) / 4 =(1.177*1.016)/4

= 0.298kNm

Bending Moment at A, M_A= 0 kNm

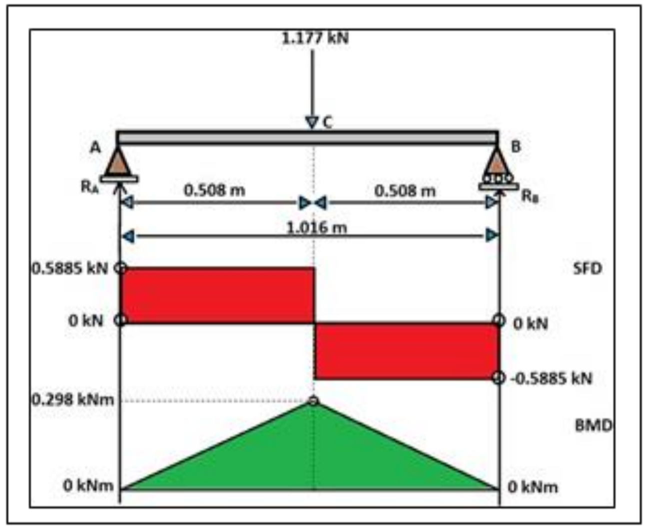

Fig. 1 Shear force and Bending moment diagram of Simply Supported Beam

Fig1 represents the shear force and bending moment diagram of simply supported beam which is connecting therod of the elliptical cycle.

MaterialUsed: **AISI1018 (MildSteel)**

Modulus of Elasticity, E = 205 GPa = 2.05 *10^{11} N/m^2 - (i)

AreaMomentofInertia (Solidrod),I = (π/64)*d^4

=(π /64) *$(0.02)^4$

=7.84* $10^{-9}$$m^4$(ii)

c) Cripping Load: To find cripping load,

Load, $P_{cr}= (\pi^2 * E * I) / le^2$

Effective Length, le = 2* l (one end hinged and another end free) = 2* 1.016 =2.032 m

Pcr = (π^2 *2.05 * 1011 * 7.84 * 10^{-9}) / 2.032^2 = 7798.4 N

Safe load = P_{cr} / Factor of safety

Factor of Safety, FoS = 3

Safe load = 7798.4/ 3 = 2599 N = 2.599 k N

The load that is going to be applied by pedelingis 1.177 k N, which is lesser than the safe load. Therefore, the design is safe.

B. Frame Rod Calculations

Let us consider the middle rod, i.e., the frame rod, which acts as the entire load-carrier and the rail holder to be a fixed beam. Since the rail is arc welded at two points of the middle rod, the weight of the rail and the person was riding the cycle act as equal halves at the two points of the middle rod.

Length of the rod, l = 0.915 m

Inner Diameter, d_i = 0.026 m

Outer Diameter, d_o= 0.03 m

Point loads, P = User load + Rail load (kN)

= 1.177 + 0.039 = 1.216kN

Since point load is acting at two points:

P_1 = 1.216/2 = 0.608 kN

P_2 = 1.216/2 = 0.608kN

Distances of the Point load from A;

AC, a = 0.076 m

AD, b = 0.839 m

Fixed end moments,

$M_{A1} = (W*a*b^2)/l^2$

$= (0.608*0.076*0.839^2) / 0.915^2 = 0.0389$ k N m

$M_{B1} = (W*a^2 *b)//l^2$

$= (0.608*0.076\ ^2*0.839) / 0.915^2 = 0.0035$k N m

Since similar load is applied and only the distances are opposite;

$M_{A2} = (W*a*b^2)/l^2 = 0.0035$k N m

$M_{B2} = (W*a^2 *b)//l^2 = 0.0389$ k N m

$M_A = M_{A1} + M_{A2} = 0.0389 + 0.0035$

= 0.0424 k N m ------------------ (a)

$M_B = M_{B1} + M_{B2}= 0.0035 + 0.0389$

= 0.0424 k N m ------------------ (b)

Bending Moment due to vertical loads,

$R_B + R_A = 0.608+0.608$

$R_B + R_A = 1.216$ ------------------ (c)

Moment about A,

$R_B * 0.915 = (0.608 * 0.839) + (0.608 *0.076)$

R_B = 0.608 k N

$R_A = 1.216 – R_B$ ------------------ from (c)

R_B= 0.608 k N

a) Bending moment diagram: Find Bending moment,

Bending Moment at A, M_A = 0 kNm

Bending Moment at C, M_C = 0.608*0.076

= 0.0462 kNm

Bending Moment at D,

MD = (0.608*0.839) -(0.608*0.076) = 0.463kNm

Bending Moment at B, M_B = 0 kNm

Shear force due to vertical loads,

$0.608*0.839 + 0.608*0.076 + M_B = M_A + R_B (0.915)$

$0.608*0.839 + 0.608*0.076 +42.36 = 42.36 + R_B (0.915)$

------------------ from (a&b)

R_B = 0.608 kN

$R_A = 1.216-R_B$ ------------------ from (c)

R_A = 0.608 kN

b) Shear force diagram: To find shear force,

Shear Force at A, F_A = R_A = 0.608 kN

Shear Force at C, F_C = R_A - 0.608 = 0 kN

Shear Force at, D,F_D = R_A - 0.608 - 0.608

= -0.608 k N

Shear Force at B, F_B = - R_B = - 0.608 kN

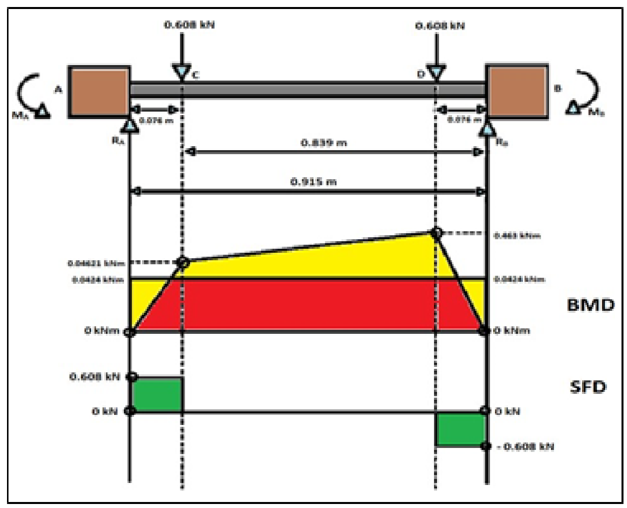

Fig. 2 Shear force and bending moment diagram of Fixed Beam

Fig 2 represents the shear force and bending moment diagram of the fixed beam, which is nothing but a single frame rod representation.

Material Used: AISI 1018 (Mild Steel)

Modulus of Elasticity, E = 205 GPa

$= 2.05 *10^{11}N/m^2$

Area Moment of Inertia (Hollow rod),

$I = (\pi / 64) *(d_o^4 – d_i^4)$

$= (\pi / 64) * (0.034 - 0.0264)$

$= 1.732*10^{-8}\ m^4$

c) Crippling Load: To find crippling load,

Load, $P_{cr} = (\pi^2 * E * I) / l_e^2$

Effective Length, $l_e = l/2$(both the ends are fixed)

$= 0.915/2 = 0.4575$ m

$Pcr = (\pi^2 * 2.05 * 10^{11} * 1.732*10^{-8}) / 0.4575^2$

= 167.25 k N

Safe load = P_{cr} / Factor of safety

Factor of Safety, FoS = 3

Safe load = 167.25/ 3 = 55.75 k N

The load which is going to apply is 1.216 k N which is around 2.2% of the entire load the rod could withstand. Therefore, the design is safe.

C. Angles and Forces involved in Slider crank mechanism

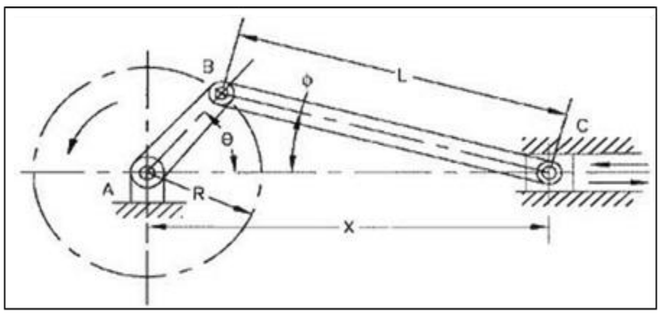

Fig.3 Slider Crank Mechanism

Fig 3 represents the slider crank mechanism along with nomenclature

Radius of the crank,r = 0.3429 m

Length of the connecting rod,l = 1.016 m

Wheel radius, r_w =0.2032 m

Assuming the cycle speed = 3km/hr = 0.833m/s

Angular velocity of cycle wheel,

ω = cycle speed/$(3.6*r_w)$

= 0.833/(3.6*0.2032)

= 1.138 rad/s

Obliquity ratio, n = l/r

= 1.016/0.3429

= 2.96

a) Crank angle

Velocity of the slider, $V = (\omega * r)(\sin \Theta + (\sin 2\Theta / 2n))$

$dV/d\Theta = (\omega * r)(\cos \Theta + (\cos 2\Theta / n))$

At maximum velocity, Acceleration$(dV/d\Theta) = 0$;

$0 = \cos \Theta + (\cos 2\Theta / 2.96)$

$2 \cos 2\Theta + 2.96 \cos \Theta - 1 = 0$

$\cos \Theta = 0.283 | \cos \Theta = -1.76$

$\Theta = 73.56$

Θ is Slope of the rod

Velocity of the slider, $V = (\omega * r)(\sin \Theta + (\sin 2\Theta / 2n))$

= (0.5946*0.3429)(sin73.56 +(sin73.56/(2*2.96)))

V = 0.4374 m/s ------------- (2)

b) Angular velocity of connecting rod

$\omega_n = (\omega * \cos \Theta)/n$

= (0.5946*cos73.56)/2.96

= 0.0568 rad/s

c) Angular acceleration of connecting rod

$\alpha_n = (\omega^2 * \sin \Theta)/n$

$= (0.5946^2 * \sin 73.56)/2.96$

$= 0.1146 rad/s^2$

d) Crankpin effort

$F_T = (F / \cos \Phi) * (\cos(90 - (\Theta + \Phi)))$

Φ is Angle between the connecting rod and slider

= (1.277) * (cos(90-(73.56+22.9))

= 1.269 k N

e) Crank effort

Crank pin radius, r_{cp} = 0.06 m

$T_{cp} = F_T * r_{cp}$

= 1.269 *0.06

= 0.0761kN m

f) Force required to slide the member

Coefficient of friction, μ = 0.065

Structural load = 30 % of F

= 0.3* 1.177

= 0.353k N

Total load, F = 1.177+ 0.353 =1.53kN

$F_s = \mu * F$ = 0.065 * 1.53= 0.09945 kN-------------- (3)

D. Torque calculation

$T = F_S * r_w$

=0.09945*0.2032 -------------------- from (3)

= 0.02020 k-Nm

The torque of a normal cycle will be between 30 to 40N m. Since this is an elliptical cycle wherein one motion is translated into another (trekking to pedaling), the torque obtained is considerably less, i.e., 20Nm.

E. Float Calculations

To enable the cycle to float, two heavy tubes are affixed to either side of the cycle.

Typical air pressure, p_a= 15 psi

Typical heavy vehicletyre pressure range, p_t = 116 -130 psi Let us assume p_t =120 psi

Expansion factor , $e_t = (p_t + p_a) / (p_t - p_a)$

$= (120+15) / (120-15)$

$= 1.28$

Tyre tube diameter ,D_{tube} = 1 m

Cross sectional width,w_{cr}= 0.275 m

Cross sectional height,h_{cr}= 0.25 m

Volume inside the tube,$V_T = \pi * D_{tube} * w_{cr} * h_{cr}$

$= \pi*1*0.275*0.25$

$= 0.2158\ m^3$

No. of tubes used, nt= 2

$VT = 0.2158 * n_t * e_t$

$= 0.2158 * 2 * 1.28$

$= 0.5524\ m^3$

Density of water, ρ_w= 1000kg/m^3

Overall Buoyancy, $F_{By} = V_T * \rho_w * 9.81$

$= 0.5524 * 1000 * 9.81$

$= 5.419$ k N

It concludes that the fluid (water) can exert a force of 5.419 kN opposite the tyre tube, enabling it to float in a considerable depth carrying a load of 200 kg. In terms of force, it is just 1.962 k N which is around 36 % of the entire load-carrying capacity of the float over the fluid. Therefore it won't sink

III. DESIGN AND SPECIFICATIONS

A. Individual Components

The components have been designed individually and assembled using Autodesk Fusion 360 software.

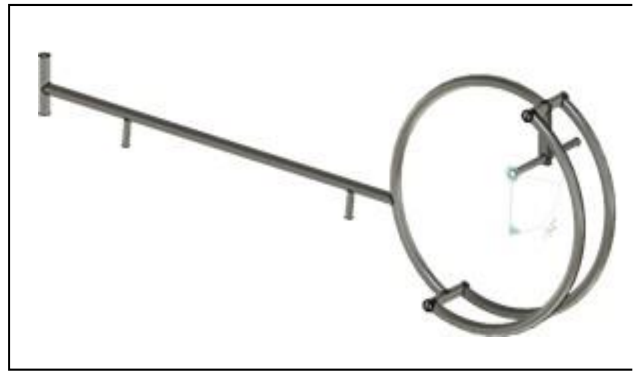

Fig. 4Body of the bicycle

Fig 4 represents the frame rod attached with the curvature attachment. The bicycle's body was designed by keeping in mind the adapted pedaling and the wheelbase, fixed initially as 60 inches. It was also designed keeping in mind that the rail and the chain wheel had to be attached to the body. The wheel diameter was fixed to be 16 inches. The diameter of the wheel chosen is slightly less than the normal cycle diameter since the pedaling involved here is different and would be better if it is as close as the ground.

Fig. 5Foot setup

Fig 5. represents the handlebar attachment that comprises the entire front setup. The front setup consists of a handlebar and a rod that supports it. The rod is slightly bent towards the driver to make a comfortable holding for the driver. It is kept at the height of two feet from the point on the central body.

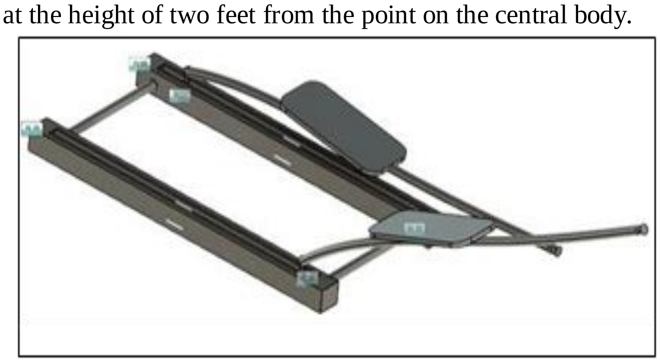

Fig.6 Rail and connecting rod attachment

Fig 6 represents the rail attachment along with the slider connecting rod by means of ball bearing, which rotates along with the slider. The rail length was fixed considering the average walking movement of a human being, and the value is 27 inches. An additional 1.5 inches on either side is given to attach it to the body of the bicycle. Two rails are at 6.5 inches from the center. The chain wheel is synchronized with the chain along which it translates the motion from crank to rear-wheel rotates with respect to the path. Due to the rotation of the sprocket wheel rear wheel also rotates. The chain wheel is designed with 44 teeth and the sprocket with 18 teeth. So, the sprocket ratio is 2.44.

B. Assembly of individual components

Fig 7 represents the entire assembly of the elliptical cycle. The designed individual components are assembled, and the motion links have been established between the components to check if it works properly.

The mechanism was achieved by manually moving the connecting rod in contact with the slider. This is done to check whether the links and assembly of parts are mated properly and are in line with the axis. In the slider-crank mechanism, when the slider moves in a to and fro motion, the connecting rod connected to the slider will be pushed and pulled forward and backward, respectively. The crankshaft connected to the connecting rod by means of a crank pin will rotate one complete revolution for one forward and one backward stroke. The purpose of testing motion links is to check whether this mechanism is achieved. The parts in the assembly were mated properly, and the alignment of the front and rear wheels was intact. Thus, the design was completed with specific dimensions that enabled the Amphi- elliptical cycle to be practically fabricated.

Fig.7Assembly of elliptical bicycle

IV. FABRICATION

The material is chosen for building the elliptical cycle frame was Mild Steel of grade AISI 1018 due to its prominence in building the bicycle frame. Since the frame rod is a single rod that interconnects the front and rear side, a hollow mild steel rod of 2m was used.

The rail comprises a ball bearing that slides over the rail slot. It is connected with the connecting rod, which is used to achieve the sliding motion. The rear end of the connecting rod is joined with the crank rod, which rotates the sprocket. The rail on either side is 30 inches in length and 13 inches apart from each other.

Fig.8 Connecting rod attached with rail

Fig 8 shows the connecting rod attached to the rail at one end, the crank at the other end, and the foot rest attached to the connecting rod at the center. nA footrest is attached at the center of the connecting rod to keep the foot on the pedal. The length of the connecting rod is 40 inches.

Fig. 9 Body of the bicycle

Fig 9 represents the fully fabricated elliptical cycle and support wheels to achieve balance on either side. The handlebar is affixed to the front portion of the elliptical cycle, considering that the elliptical bicycle is going to be driven while standing. Therefore, a lengthy rod with a handle attachment is added. After complete fabrication, the synchronization of the connecting rod, slider, and crankshaft was checked. Thus, the slider-crank mechanism which was incorporated in the elliptical cycle was achieved.

Fig. 10 Connecting rod attached with rail

Fig10 represents the final product of the elliptical bicycle along with float attachment. Two truck tyre tubes were attached to the elliptical bicycle on either side to enable the elliptical bicycle to float. The deflated tubes were inserted inside the flat metal band and then inflated with suitable pressure. Further, the entire fabrication unit was tested in a water body to check whether the cycle floats. Thus, the floating mechanism was achieved, and as expected, the float and the bicycle never sunk in water.

V. CONCLUSIONS

The design phase was completed and simulated for checking the intact synchronization. The dimensions were finalized by consulting with fabricators who had expertise in this field. The floating test was conducted, and it was found that the entire weight was acting on the rear side of the vehicle resulting in the rear side sinking in water when the person cycling tries to pedal the cycle. This defect was overcome by deflating the offsetting the tube slightly backward by deflating and re-inflating the tube after it was placed in an offset position. One more problem which arose while testing on land was the improper engagement of the chain over the chain wheel. This defect was overcome by reducing the chain length. In addition to that, to make the chain rotate along the path of the chain wheel, a support structure is welded along the chain's path so that the chain wheel tooth is properly attached with the chain and thereby the removal of chain from the chain wheel can be avoided. Thus, the Amphi-elliptical bicycle was fabricated, and the purpose was achieved.

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