Force analysis on wheels and suspension in HPV

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Abstract:

Human powered transportation is the movement of people or good using the strength of the human body. Unlike animal driven transport, human powered transport in the form of walking, running and swimming has existed since time immemorial. New technology has made it possible for the machines to increase human capacity. While motorization has amplified both swiftness and load efficiency, many modes of human-powered transport remain common for low cost, leisure, physical work, and effect on environment. Human transportation is often the only type possible, especially in underdeveloped or inaccessible regions, and if well planned and developed, it can be a more sustainable form of transportation. Force analysis on the wheels and suspension system on a human-powered road vehicle (HPV) is being carried out in the present study.

1 Introduction:

Human powered vehicle, it is also denoted by HPV. The term HPV includes all the vehicles that are powered by muscle strength. HPV is a vast area and it can be categorized into various categories [1]. The largest of all is the bicycle. But one can find Human Powered Vehicles in Air, under the water or in the rail. Some HPVs are built for the competitions to get faster and faster, but others are for daily use like rickshaw. A real HPV can be power-driven by an electric engine also. Some examples are Land HPV-Recumbent bicycle, Land HPV-Velomobile, Water HPV, Rail HPV and Air HPV.

As shown in Figure 1 the Human Driven Vehicle plays a role in the sustainable mobility. As part of the push towards sustainable transport and urban mobility activities, increased use of the cycle is widely advocated as a component in this change in paradigm [2-3]. New advances in bike technology are beginning to implement new bike classes and other Human Powered Vehicles as alternatives within a broader advocacy of urban mobility cycling and which can give users advantage and greater opportunities. When an HPV is used as a means of transportation, the driver not only loves the trip, but also gets some other benefits that have never even been noticed. Various components of HPV are represented in Table 1.

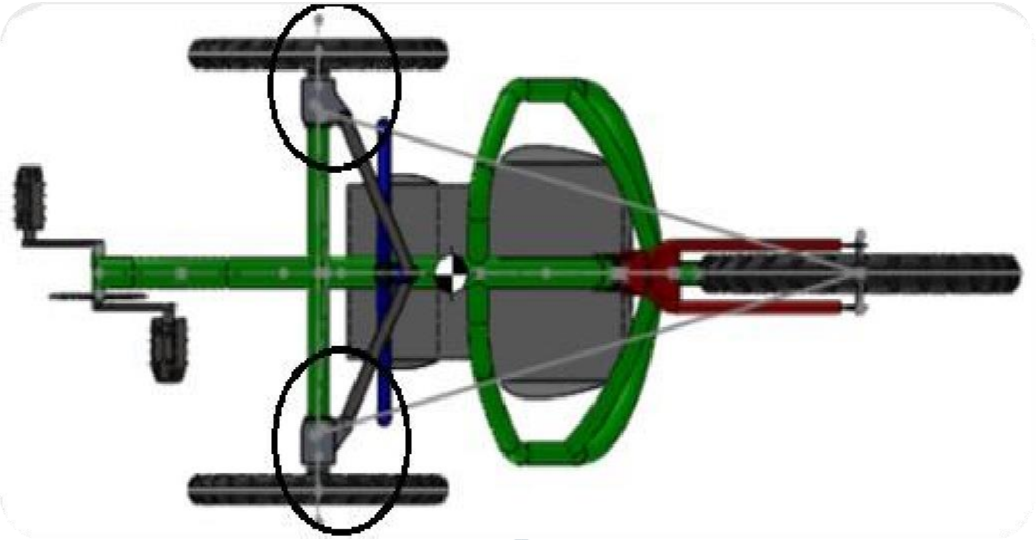

Figure 1: Human Powered Vehicle

Table 1: Components in a human powered vehicle

S No.	Components	S No.	Components
1	Frame	10	Nut, Bolt, Cotter pin
2	Wheels	11	Bearings
3	Chain	12	Fairing
4	Gear shifter	13	Fork, U-joint
5	Derailleur	14	Brake cables
6	Pedals	15	Disc brake setup
7	Sprocket	16	Brake levers
8	Gear cassette	17	Horne
9	Bottom bracket	18	Seat and seat belt

2 Force Calculations:

2.1 Suspension:

Suspension is one of the most important subsystems of the vehicle. It supports the vehicle weight, separates the vehicle frame from road turbulences, and maintains the contact between the tire and the road surface also it improves stability and ride comfort.

In the present work, a monoshock rear suspension was used with the main aim of maintaining contact among rear wheel and road surface for maximum time, which results in better transmission efficiency. It also helps to maintain correct CG height while travelling over various road disturbances. The vehicle was designed to travel on public roadway therefore the suspension is allows a wheel travel of about 4.5 cm and the suspension travel of about 3 cm these values were chosen keeping in mind the road profile and driving conditions. Natural frequency of 1.3 Hz is chosen for ride comfort.

Force on wheels

The force on the wheels is the weight of the vehicle and the driver,

Force= (32+65)*9.81= 951.57 N

Force on rear wheel= 951.57*25/100= 237.89 N (weight distribution (Front: Back) = 75:25)

Load transfer during acceleration

Load transfer during acceleration= a*w*h/l = 2.8*97*0.4133/1.06 = 105.90 N

Total Force on rear wheel = 237.89+105.90 = 343.7925 N

Force on suspension = force on wheel/motion ratio (motion ratio=30/45= 0.67) F2

= 343.79/0.67=513.11 N

Wahl's Factor K_w

K_w = ((4C-1)/ (4C-4)) + (0.615/C)

= (4*7.5-1)/ (4*7.5-1) + (0.615/7.5)

=1.20

t = K_w(8*PC/pi*d^2)

440 =1.20(8*513.11*7.5/3.14*d^2)

d = 5.17mm =6 mm

D=C*d=8*6=48 mm

Number of Active Coils

Deflection=8*D^3*N*P/G*d^4

30=8*(48/1000)^3*N*513.11/76.92*10^6*(6/1000)^4 N=

6.58= 7

Total Number of Coils

Number of active coils + 2 N_t

= N+2=7+2=9

Solid Length

$Sl=N_t*d$

Sl=9*20=180 mm

Actual Deflection

Δact = 8*P*D^3N/(G*d^4)

= 40.98 mm=41 mm

Axial Gap

$g = (N_t-1) * (1\ mm)$

= 8mm

Free Length

$L_f = \Delta act + g + sl$

=41+8+180=229 mm

Stiffness

Spring stiffness (k) (acc. to impact force)

k =P/x =513.11/30 = 17.10 N/mm=1710 N/m

Desired Natural Frequency (f) = 1.3 Hz

Initial Stiffness According to Desired Frequency, K_s

$= 4\pi^2 f_r^2 m_{sm} MR^2$

{K_s = spring rate (N/m) m_{sm} = Spring mass (kg) f_r = Ride frequency (Hz) MR = Motion ratio (Wheel/Spring travel)}

$K_s = 4\pi^2*1.3^2*100*0.67$ (m_{sm}= 100 kg)

K_s=4470.14 N/m

2.2 Forces on Wheels:

The forces on steering system originate from road and tire interface. The forces are measured at centre of contact. Given below Table 2 representing various forces acting over the wheels which results in different types of reactions over the wheel.

Table 2: Forces acting on wheels

Type of Force	**Reaction on the wheels**
Tractive Forces	Overturning moment
Normal force	Aligning torque
Lateral force	Overturning moment

Load transfer during braking in downhill condition:

$W_f = W\,[c*\cos(\Theta) - ax*h/g + h*\sin(\Theta)]/L$

$= 32[0.7244*\cos(5) - 7.6*0.4266/9.81 + 0.4266*\sin(5)]/1.0668$

$= 12.846$kg

Total force on front =12.846+80=92.846 kg

WVL = WVR= $W_f/2$=46.423 Kg

Vertical Force

Vertical Forces on both tires =$W_{VL}=W_{VR}$=455.409 N

Moment Due to Vertical Forces:

$M_{VL} = (F_{VL}+F_{VR}) * d*\sin(\lambda)*\sin(\delta)$

$= (455.409+455.409) *0.01*\sin(3) *\sin(28.5)$

$= 0.2274$ Nm

Lateral Force:

$F_{YL} = F_V*C_S*\alpha \quad = 87.438$N

Moment due to Lateral Forces:

$M_L = (F_{YL}+F_{YR})*$Tire Radius $*\tan(v)$

$= (87.438+87.438)*0.254*\tan(5)$

$= 3.886$ N-m

Moment Due to Aligning Torque:

$M_{AT} = (M_{VL}+M_{VR})*\cos\sqrt{[(\lambda^2+v^2)]}$

$= (0.2274+0.2274)*\cos[\sqrt{[(7^2)+(5^2)]}]$

$= 0.45244$ N-m

Total Kingpin Torque $= M_V + M_L + M_{AT}$

$= 4.56584$ N-m

The values obtained through above calculations meet the requirements mentioned above and hence the steering design was finalized.

Conclusion:

1. After careful calculation, optimization and analysis of the suspension geometry natural frequency of system was decided to be kept at 1.3 Hz and stiffness of suspension was decided to be 4470.14 N/mm. The final suspension travel was kept as 30mm, motion ratio as 0.67.
2. The vertical and lateral force on the wheel were 455.409N and 87.438N respectively. The total kingpin torque was calculated to be 4.56584 N-m.

References:

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