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# Design Optimization of Speed Ratio for Conventional Chain Drive Used In Tricycle

**Chetan A. Samarth, A. K. Mahalle**

***Abstract** - the present paper is work to optimize the speed ratio done to improve the efficiency of cycling. Various design changes in the components of chain drive mechanism of bicycle has been done to increase the mechanical advantage. In the previous study the mechanical efficiency of cycling was investigated with new developed pedal-crank prototype (PP). The efficiency values were compared with those obtained, in the same experimental conditions and with the same subjects, by using a standard pedal–crank system (SP). the improvements in the efficiency of cycling observed in this study were rather small (about 2%) and apparent only at the higher load tested . further study also attempted to design a non-circular chainring that increases the crank power by 2.9% compared to a conventional circular chainring. Increase in the average crank power was the result of the optimal chainring slowing down the crank velocity during the down stroke (power phase) to allow muscle to generate power longer and produce more external work but the data also showed that the chainring with higher eccentricity increased negative muscle work following the power phase due to muscle activation-deactivation dynamics. This paper proposes to measure the optimal gear ratio as well as design of sprockets for the drive system of tricycle. The study provides guideline, design specification and performance measure to design efficient drive system.*

*Keywords: mechanical efficiency, non-circular chainring, pedal-crank prototype (PP)*

## I. INTRODUCTION

Passenger tricycle in India also known as cycle rickshaw is the major means of transport of passenger and other goods. It is maneuverable, completely non-polluting and hence environment friendly means of transport. In the narrow lanes of the town and cities probably they are the only transport system to provide point to point travel. The existing rickshaws are so poorly designed that running them takes a heavy toll on the health of the rickshaw puller.

The existing cycle rickshaw has hardly changed since it was introduced in India in early 1920's from Far East. The gearing and the mechanical advantage of the pedal is very poor. Hence the rickshaw puller has to work hard while climbing even a slight slope. A common sight is of the rickshaw puller getting down and pulling on the foot the rickshaw with the passengers

The conventional drive mechanism of tricycle is provided with one set of sprocket, which gives speed ratio of two between input and output. This speed ratio is fixed for all loading conditions. More effort is required to the puller in starting from the rest or going up. Hence it is necessary to analyse various factors responsible to increase the mechanical efficiency.

**Fig1. Passenger tricycle used in India**

Various researches have been done to improve the cycling efficiency of the bicycle and tricycle. The factors which other researchers has discussed are

- crank length
- optimal chainring shape
- pedalling rate
- Pedal speed etc.

Paola Zamparo, Alberto E. Minetti, Pietro E. di Prampero [1] developed the new prototype of the pedal crank. The main feature of this prototype is that its pedal crank length changes as a function of the crank angle being maximal during the pushing phase and minimal during the recovery one. The efficiency values of new pedal crank prototype (PP) were compared with the standard pedal-crank system for same experimental condition and with the same subject.

Improvement in the efficiency of cycling observed in the study were about 2% and apparent only at higher load tested, they indeed show that transmission efficiency of cycling could be further improved by means of a pedal-crank of variable length.

Jeffery W. Rankin, Richard R. Neptune [2] studied to determine if cycling performance (i.e., maximal power output) could be improved by optimizing the chainring shape to maximize average crank power. The optimization identified a consistent non-circular chainring shape at pedaling rates of 60, 90 and 120 rpm with an average eccentricity of 1.29 that increased crank power by an average of 2.9% compared to a conventional circular chainring.

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The increase in average crank power was the result of the optimal chainrings slowing down the crank Velocity during the downstroke (power phase) to allow muscles to generate power longer and produce more external work.

J. C. Martin, W.W. Spirduso [3] studied the effect of cycle crank length on maximum cycling power, optimal pedaling rate and optimal pedal speed, and to determine the optimal crank length to leg length ratio for maximal power production. Trained cyclist performed maximal inertial load cycle ergometry using crank lengths of 120,145,170,195 and 220 mm. Maximum power ranged from a low of 1149 W for the 220-mm cranks to a high of 1194 W for the 145-mm cranks. Power produced with the 145 and 170-mm cranks was significantly ($P<0.05$) greater than that produced with the 120 and 220-mm cranks. The optimal pedaling rate decreased significantly with the increasing crank length, from 136 rpm for the 120-mm cranks to 110 rpm for the 220 mm cranks. Conversely optimal pedal speed increased significantly with increasing crank length, from 1.71 m/s for the 120 mm cranks to 2.53 m/s for the 220-mm cranks.

These data suggest that pedal speed (which constrains muscle shortening velocity) and pedal rate (which affects muscle excitation state) exerts distinct effect that influence muscular power during cycling.

Danny Too and Gerald E. Landwer [4] discussed about the factors affecting performance in human powered vehicles (HPV). The purpose of this paper is two-fold: (1) to provide information, from a biomechanical and physiological perspective, how muscle force is produced and modified; and (2) to examine how the muscle force produced interacts with external mechanical factors to produce power.

Ernst Albin Hansen, Lars Vincents Jorgensen, Kurt Jensen, Benjamin Jon Fregly, Gisela Sjogaard [5] The study tested the hypotheses that during cycling with sub-maximal work rates, a considerable increase in crank inertial load would cause (1) freely chosen pedal rate to increase, and as a consequence, (2) gross efficiency to decrease. Furthermore, that it would cause (3) peak crank torque to increase if a constant pedal rate was maintained. Subjects cycled on a treadmill at 150 and 250 W, with low and high crank inertial load, and with preset and freely chosen pedal rate. Freely chosen pedal rate was higher at high compared with low crank inertial load. Notably, the change in crank inertial load affected the freely chosen pedal rate as much as did the 100W increase in work rate. Along with freely chosen pedal rate being higher, gross efficiency at 250W was lower during cycling with high compared with low crank inertial load. Peak crank torque was higher during cycling at 90 rpm with high compared with low crank inertial load.

From the above researches it was found that speed ratio is the factor to be considered for the analysis of the drive efficiency. New drive components modeled in computer aided design (CAD) software after analysis of optimum gear ratio for the conventional drive in tricycle.

## II. MAIN BODY OF THE PAPER

### A. *Existing gearing system of tricycle*

Various types of designs of tricycles are used in all over India. Considering one of passenger tricycle conventional drive system is used in it which is provide with design dimensions as follows

- Weight of cycle rickshaw = 951.57N
- Drive used in tricycle:- roller chain drive
- Chain used:- riveted roller type with single strand (simplex)
- Gear ratio or speed ratio (front chainwheel/freewheel) = 2
- Length of the crank arm = 180mm
- No. of teeth on chainwheel(front sprocket) = 48
- No. of teeth on freewheel(rear sprocket) = 24

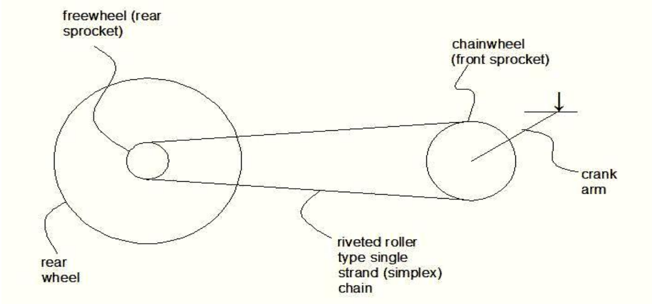


**Fig1. Schematic representation of the conventional chain drive used in tricycle**

### B. *Calculations for Optimal speed ratio for various loading conditions*

Since the drive used in tricycle is conventional chain drive the speed ratio of the drive train is fixed i.e 2. Force required on the pedal is more with this speed ratio forcing the puller to get down and pull it on the foot. Hence it is required to analyze the speed ratio or gear ratio to find out the optimal one.

The loading conditions applied are

1) Vehicle at full load and zero gradient
2) Vehicle at full load and $2^0$ gradient

Considering the first loading condition total tractive effort required on the rear wheel of the tricycle is calculated.

Inputs are

- Gross weight of the tricycle acting on the rear wheels (W)= 1962 N
- Radius of the rear wheel $r_w$ = 350mm
- Desired maximum speed of the tricycle ($V_{max}$)= 2m/s
- Desired acceleration time ($t_a$) = 10 sec
- Gradient ($\alpha$)= $0^{\circ}$
- Coefficient of rolling resistance between tire and road $C_{rr}$ =0.017(contact surface asphalt)

Total tractive effort (TE) is the addition of rolling resistance (RR), gradient resistance (GR) and acceleration force (FA)

i.e. $\mathrm{TE} = \mathrm{RR} + \mathrm{GR} + \mathrm{FA}$ (1)

Now, rolling resistance $(\mathrm{RR}) = \mathrm{W} \times \mathrm{C_{rr}}$ = 33.35N

Gradient resistance is given as $GR = W \times \sin \propto$

Since $\propto = 0^{\circ}$ therefore GR = 0

Accelerating force $FA = W \times \frac{V_{max}}{g \times t_a}$

= 40N

Therefore Total tractive effort (TE) = 73.35N

Here TE is the force required at the rear wheels of the tricycle to drive it with the desired speed in desired time.


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Now in chain drive used in tricycle the force applied to the pedal is transferred to the rear wheel

Hence the force on the pedal is calculated by formula [6]

$$F_R = \left(\frac{F \times r_C}{r_W}\right) \times \left(\frac{r_2}{r_1}\right) \quad (2)$$

Where $F_R$ is force transmitted at the rear wheels of the tricycle.

$r_c$ - the length of the crank arm.

$r_2$ - the radius of the rear sprocket

$r_1$ - the radius of the front sprocket or chainwheel

F - The force on the pedal

Therefore the force required on pedal calculated as

$$F = \left(\frac{F_R \times r_W}{r_c}\right) \times \left(\frac{r_1}{r_2}\right) \quad (3)$$

Here $F_R$ is the total tractive effort TE.

And radius of the front and rear sprocket can be calculated by

$$R = \frac{P}{\sin\left(\frac{180}{N}\right)} \Big/ 2 \quad (4)$$

Where P is the pitch of the chain
R is the radius of the sprocket
N is number of teeth on the sprocket

Hence the force on the pedal for the first loading condition is F= 284.29N

The mechanical advantage of the drive is $MA = \frac{F}{F_R} = 0.25$

Since in the loading condition the desired speed of tricycle is given the pedaling speed can be found as follows

$$V = r \times \omega \quad (5)$$

Where V represents the linear speed of the wheels, r represents radius of wheel and $\omega$ is the angular speed of wheel.

Considering this for the rear wheels of the tricycle then the angular speed of the rear wheel will be

$\omega = \frac{V}{r}$ = 5.7 radians/sec.

Since the rear sprocket is attached directly to the rear wheel axle it rotates as that of rear wheel hence each revolution of the rear wheel is a revolution of sprocket.

Then the angular speed of the rear sprocket will be same i.e $\omega_{rs}$ =5.7radians/sec

Radius of the rear sprocket $r_{rs}$ from the equation (3) is 0.048m

Therefore $V_{rs} = \omega_{rs} \times r_{rs}$ = 0.273m/s

Hence chain and front sprocket will also have the linear speed 0.273m/s

And Radius of the front sprocket $r_{fs}$ from the equation (3) is 0.097m

Thus $\omega_{fs} = \frac{V_{fs}}{r_{fs}}$ = 2.81 radians/sec

i.e. $\omega_{fs}$ = 2.81 radians/sec=0.44rev/sec=26.4rpm≈27rpm

Hence for tricycle speed of 2m/s the pedaling rate of 27 revolutions per minute is required.

The process is repeated for the second loading condition all the other parameters are kept same only considering 2° gradient.

*C. Analysis of optimal speed ratio for given conditions*

On the basis of the above calculation method various parameters are calculated for different speed ratio and it is compared with the existing and analyzed.

Table 1, 2 shows the results of the calculation for the various reducing speed ratios. In this speed ratio is reduced to that of the existing to increase the mechanical advantage. Difference in the diameter of the sprocket which can express as speed ratio depends on the number of teeth available on the front and the rear sprocket. And the sprocket which are generally used is available for no. of teeth (Front chainwheel: 48,46,44,42 etc and rear freewheel: 26, 24, 22 etc).

**Table1. Analytical results of the first loading condition**

| No. of teeth on chainwheel: no. of teeth on freewheel | Speed ratio | Force acting on pedal in Newton (N) | Pedal rate RPM | MA | Power input to the pedal watts |
|---|---|---|---|---|---|
| 48:24 | 2 | 284.29 | 27 | 0.257 | 144.68 |
| 46:24 | 1.91 | 272.12 | 28 | 0.269 | 143.62 |
| 42:22 | 1.90 | 267.71 | 28 | 0.270 | 142.84 |
| 44:24 | 1.83 | 260.74 | 29 | 0.281 | 142.53 |
| 42:24 | 1.75 | 249.27 | 31 | 0.293 | 145.65 |
| 44:26 | 1.69 | 240.73 | 32 | 0.304 | 145.20 |

Table1. Shows the analysis of the results for the factors on which the efficiency of the drive system depends for first loading condition (zero gradient).

Table2. Represents the same for the second loading condition (considering 2° gradient)


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**Table2. Analytical results of the second loading condition**

| No. of teeth on chainwheel: no. of teeth on freewheel | Speed ratio | Force acting on pedal in Newton (N) | Pedal rate RPM | MA | Power input to the pedal watts |
|---|---|---|---|---|---|
| 48:24 | 2 | 549.55 | 27 | 0.257 | 279.69 |
| 46:24 | 1.91 | 526.89 | 28 | 0.269 | 278 |
| 42:22 | 1.90 | 524.63 | 28 | 0.270 | 276.89 |
| 44:24 | 1.83 | 504.03 | 29 | 0.281 | 275.52 |
| 42:24 | 1.75 | 481.08 | 31 | 0.293 | 281.11 |
| 44:26 | 1.69 | 465.38 | 32 | 0.304 | 280.71 |

## III. RESULTS

In the above observations it was found that with reduction in the speed ratio for the required force on the rear wheel to drive the tricycle with the desired speed in the desired time period is increased, which results in increase of the mechanical advantage (MA).Increase in the force on the pedal was 84.17N and MA was 0.304for the minimum speed ratio considered (From table2.).

It was found that up to the speed ratio of 1.83 power input to the pedal which is calculated on the basis of force on the pedal and pedaling rate is reduced up to 4.17watts which plays the important role to increase the efficiency of the drive, but further reduction in the speed ratio results in the increase of the pedal input power which apparently reduces the efficiency in spite of increase in the force on the pedal. It was due to the increase in pedaling rate with the reduction in the speed ratio for the same duration of time.

## IV. CONCLUSION

From the above result it is concluded that below the speed ratio of 1.83 the results reduces the efficiency of the drive due to increase in the pedal input power to the constant power output .hence 1.83 is used as the optimal speed ratio with 44 number of teeth on the front chainwheel and 24 teeth on the rear wheel which increases the mechanical efficiency of the existing one by 1.09%. Changes to be made in the drive are to replace the front chainwheel of 48 teeth in the system by 44 teeth chainwheel. The new sprocket of 44 teeth has been designed and the CAD model of the same has been prepared.

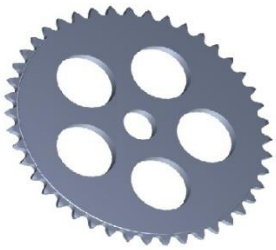

**Fig2. CAD model of the 44teeth front chainwheel**

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