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Study of performance of cycle rickshaw puller: literature review

A.K.Mahalle[1,*] and G.K.Awari[2]
[1]G.H.Raisoni College of Engineering, Nagpur.
[2]Tulsiramji Gaikwad Patil College of Engineering, Nagpur.

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ABSTRACT

The design of existing cycle rickshaw has hardly changed significantly even since it was introduced in India in early 1940’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. The work done by the various researchers has been studied and improved methodology has been suggested by the authors in future work.

Introduction

Various researches have been done to improve the cycling efficiency of the cycle rickshaw, considering human power performance, geometry of parameters of cycle rickshaw. The factors which researchers has discussed are

- crank length
- optimal chain ring shape
- pedalling rate
- Pedal speed etc.

The efficiency of the drive can be improved by optimizing these factors. Speed ratio and wheel diameter can also affect some of this factors hence it is necessary to optimize the speed ratio and wheel diameter of the cycle rickshaw. Present speed ratio and wheel diameter of the cycle rickshaw is 2 and 700 mm respectively.

A lot of studies have been undertaken in the past related to humane performance in cycling. In conventional cycling, there are a large number factors affecting the performance in cycling. Researcher of human powered vehicles often focuses on how resistive forces (friction, drag) can be minimized, as opposed to how propulsive forces can be maximized. How to maximize propulsive forces through vehicle design is not often understood because of a complex inter action between internal biomechanical factors (muscle forces/torque/power production) and external mechanical factor (chain wheel size/crank length/wheel diameter etc). Understanding the biomechanics of bicycle pedalling is important in elimination of overuse injuries in the knee incurred from the pedalling activity, using stationary ergometer as a form of physical therapy if bicycling biomechanics were better understood, by developing the science of bicycling biomechanics which would lead to techniques for improving performance in competition. Information needed to understand the pedalling process includes identifying the leg muscles which participate, the pedal loads, and the kinematics of leg segments.

The researchers have studied the effect of variables on bicycling performance to find out the optimal solution . The basic approaches taken are summarized under three main areas, (1) human performance testing, (2) maximizing power output, (3) optimization analysis. Naturally selected pedalling rates are also called preferred pedalling rates.

Human Performance Testing:

The interrelationship between pedalling rate, power output, and energy expenditure was first investigated using bicycle ergometry as a model for recreational bicycling by Seabury [1]. It is to be seen that this experimentation was conducted indoor on a monark bicycle ergometer which pedals on a heavy steel crankset.

He studied performance of three young male subjects rode a Monark bicycle ergometer at eight pedalling rate in increments of 10 and four power outputs All eight pedalling rates were performed at each of the four workloads, yielding 32 different combination of rate and workload. These combinations, plus six random repeats to ascertain the reliability of the individual measurements, resulted in a total of 38 observations for each subjects.

In this experimentation, it was found that: 1) the most efficient pedaling rate exists for each power output studied. 2) the most efficient pedaling rate increases with power output and 3) there is appreciable interaction between pedaling rate and power output in achieving the most efficient rate in bicycle erogometry. The most efficient pedaling rate observed at high power outputs in the present study is considerably lower than that reported for racing cyclists by others.

In the study done by **Soden [2],** the forces the rider is expected to apply to a bicycle in a variety of common racing cycling situations was estimated. The forces resisting motion of a bicycle include rolling resistance and aerodynamic drag, together with inertia forces during acceleration and gravity forces when climbing an incline. The rider overcomes these resistances by applying forces to the pedals which are transmitted by the mechanical drive to the rear wheel.

He analyzed three cases of forces for starting, climbing and speeding In all the tests with the rider seated, the pedal loads were less than, or equal to, body weight leaving a fraction of body weight to be supported by the saddle. When speeding on a

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Tele:
E-mail addresses: a_mahalle@rediffmail.com

level ground the subject sat in the saddle and pedals steadily, keeping the bicycle vertical and adopting the crouched racing position to reduce aerodynamic drag which was the major resistance to motion. The largest pedal forces recorded were for starting on an inclined. In the climbing and starting tests, the gravity and acceleration forces were large. The rider stood on the pedal; the maximum pedal loads were considerably greater than the body weight. The forces greater than body weight to be applied is due to the following reactions. (i) Inertia force due to vertical acceleration of the body, (ii) Pulling on the handle bars, (iii) Pulling on the rear pedal.

Thus, Rider applies pedal load force to the machine as well as forces on handle bars and on the saddle. The distribution of these forces varies as rider tends to adopt different positions and riding patterns in different situation.

A new instrumentation system was proposed by **Hull [3]** to precisely measure pedal loads and pedal position. A detailed knowledge of foot-pedal interaction loads is of interest for a variety of reasons. First, foot-pedal loading is important in the study of overuse injuries which are quite prevalent, especially in the knees of riders.

Second, foot-pedal loads are necessary in the study of leg muscle fatigue. To realize maximum utilization of bicycles for practical transport, it is desirable to design the bicycle and related equipment so that leg muscle fatigue is minimized. The foot-pedal connection is the most important consideration because it dictates which muscle groups are available to power the bicycle. Pedal loading instruments, pedal loading measurements are necessary for calculating rider output power and pedalling efficiency. Knowing these variables, rider may improve their pedaling technique and decrease muscle fatigue. Third, foot-pedal loads are useful in the design of bicycle frames and bicycling equipment (e.g. pedals, cranks, chains, etc.).

In this investigation, natural riding characteristics are retained by utilizing bicycle rollers in the laboratory which does not interfere with normal pedaling. With right pedal instrumented, data were recorded over three complete revolutions at 80 rpm. The data were analyzed with specialized software. He analyses data related to various position of crank angle to study value of the normal force Fz, shear force F x wrt torque and pedaling efficiency

The investigation of several foot-pedal connection was carried by **Davis [4]** to determine their effect on rider fatigue, pedaling power and efficiency. This exercise helps in the creation of a pattern recognition scheme for detection and prevention of bicycling overuse injuries. The several foot-pedal connection used are as such, a bare pedal and soft- sole shoe, pedal with toe clips and soft- sole shoe along with leather straps to apply pre-pressure between soft- sole sand pedal, toe clips with special light weight shoe reinforced with steel spring in the sole.

A computer-base instrumentation system was used to accurately measure the six foot-pedal load components and the absolute pedal position during bicycling. The instrumentation system is extensive and meaningful biomechanical analysis of bicycling. With test subjects riding on rollers which simulate actual bicycling, pedaling data were recorded to explore following major conclusion: 1) Using cleated shoes retards fatigue of the quadriceps muscle group. 2) Overall pedaling efficiency increases with power level; 3) non-motive load components which apply adverse moments on the knee joint are of significant magnitude; 4) analysis of pedaling is an invaluable training aid. One test subject reduced his leg extortion at the pedal by 24 per cent.

The investigation was proposed by **Patterson [5]** to compare the physiological responses, biomechanical effects and objective measures during work performed with flywheel of two different weights at various pedaling rates using a Quinton Model 870 bicycle laboratory erogometer.

A maximum progressive exercise stress test was performed on each subjects using ergometer with a heavy flywheel in order to determine their maximal oxygen uptake. The result showed no statistically significant change ($p<0.05$) in $VO_{2,}$ heart rate and rating of perceived exertion of the FEI as a function of flywheel weight

Measured physiological, subjective and biomechanical indices did not change significantly with flywheel weight As the pedalling rate increases , effective application of forces to the crank arm is found to be significantly less with only a small increase change in VO_2.

The purpose of investigation by **Croisani [6]** was to isolate effects of pedal rate and brake load upon metabolic responses during bicycle ergometer work. The effects was examined by using two way factorial design. This also permits determination of any interaction of the effects of pedal rate and brake load (rate x load), that is, any power effect.

It was determined that, when the brake load is held constant, Steady-state VO_2 was found to be a quadratic function of pedal rate.Simlarly ,when pedal rate was held constant , Steady-state VO_2 was found to be a quadratic function of brake load. The effects of rate and load also significantly interact with each other ,such that the effect of one factor depends on the level of the other factor or on the power(rate x load) .It should be noted that the effect of power on energy expenditure is the interaction of the effects of pedal rate and brake load .Therefore ,these factors should not be consider as separate factor in the study of bicycle ergometer work.

The present study has shown that the interaction of rate and load effects is a quadratic (power^2) interaction. Due to these interactions, the energy expenditure at a given power depends up on the particular combination of pedal rate and brake load used, and in some instances can vary substantially.

The study of various factors was proposed by **Hull [7]** to present an integrated analysis of bicycling biomechanics where the focus is on determining the functional roles of the lower limb muscles which participate in pedaling. Subjects rode under different pedaling condition to explore how both pedal forces and pedalling rates affects the biomechanics of the pedalling process.

This work reports a new method, which consists of simultaneously measuring both the normal tangential pedal forces, the EMGs of eight leg muscles, and the crank arm and pedal angles. By modeling the leg-bicycle as a five bar linkage and driving the linkage with the measured force and kinematic data, the joint moment histories due to pedal forces only (i.e. no motion) and motion only (i.e. no pedal forces) were generated.

The Activity of eight leg muscles was monitored by **Jorge [8]** for six test subjects while pedaling a bicycle on rollers in the laboratory**.** Propulsion of a bicycle via pedalling action of a legs is caused by contraction of the leg muscles. It is important to understand which muscles are active while pedalling and the forces being developed by the muscles. Because of large difference in the regions of muscle activity from previous work[7],it was decided to repeat the electromyogram experiments to determine the regions of activity for eight muscles of the leg, to determine the effects on muscle activity using different foot-to-pedal connections, soft sole shoes without toe clips vs. toe clips and cleats, to relate muscles activity levels to average power output at constant pedalling rate ,to explore the relationship between muscle activity and seat height.

The different pedaling conditions were defined to explore a variety of research hypotheses. This exploration has led to the following conclusions.

1) Muscular activity levels of the quadriceps are influenced by the type of shoes worn and activity levels increase with soft sole shoes as opposed to cycling shoes with cleats and toe clips.
2) EMG activity patterns are not strongly related to pedaling conditions (i.e. load, seat height and shoe type). The level of muscle activity, however, is significantly affected by pedaling conditions.
3) Muscular activity bears a complex relationship with seat height and quadriceps activity level decreases with greater seat height.
4) Agonist (i.e. hamstrings) and antagonist (i.e. quadriceps) muscles of the hip/knee are active simultaneously during leg extension. Regions of peak activity levels, however, do not overlap.

Joint moments are of interest because they bear some relation to muscular effort and hence rider performance In the process of bicycling, it is desirable for rider to maximize performance. In this study done by **Red Field [9],** the relation between joint moments and pedaling rate (i.e. cadence) was explored. Joint moments are computed by modeling the leg bicycle system as a five bar linkage constrained to plane motion with the fifth bar fixed in space.

Analytical results indicate that average joint moments vary considerably with changes in pedalling rate. Both hip and knee joints show an minimum average moments near 105 rotation/min for cruising cycling. It appears that an optimum rotation /min can be determined for any given power level and bicycle rider geometry from mechanical approach.

The possibility of error was studied by **Lakomy [11]** resulting from assuming the flywheel to be revolving at a constant speed and does not take into account the work required to accelerate it.

The purpose of the present study was to demonstrate, that the discrepancies in power output measurements derive from the measurement technique itself, the order of magnitude of the errors involved, a method of obtaining more accurate values of the work done and the power generated.

Function–loaded cycle ergometers are widely used to measure the work done in short-duration high-intensity exercise. This work is calculated from the product of the average values of flywheel speed and resistive load.

The magnitude of the instantaneous muscular power output at the hip, knee and ankle joints during ergometer cycling at different workloads and speeds was studied and calculated by **Ericson [13]**. He also investigated how the power production relationship between the different lower limb muscle groups was affected by changes in work load and pedaling rate.

The total work during one pedal revolution significantly increased with increased work load but did not increase with increased pedaling rate at the same braking force. The relative proportions of total positive work at the hip, knee and ankle joints were also calculated. Hip and ankle extension work proportionally decreased with increased work load. Pedaling rate did not change the relative proportion of total work at the different joints.

The present study did not reveal any increase in positive muscular work with the increased speed, which however might be revealed in future studies including an increased number of subjects and improved data collection such as automatic pedal force and kinematic recording.

In addition, one of the main drawbacks of the present method is that one can only calculate the net muscular work and not the gross work caused by co-contraction from antagonistic muscles. The possible effects of energy transfers between joints through two-joint muscles are also very difficult to estimate and control.

The relationship between the different powers liberated between joint rotation during ergometer cycling is studied by Van Ingen Schensu **[15].**This experimental analysis is widely used to measure mechanical power and efficiency of human movement.

Based on a model consisting of three rigid links, an instantaneous power equation has been deduced for ergometer cycling which shows a casual relationship between power liberated in joint rotation on the one hand and the rate of change of segmental energy plus the power transferred to the pedal on the other. It is suggested that power liberated in the joints should be considered as source of power in power equation. It is also proposed that the power should be defined as external power in this and other human movement.

An optimal control algorithm was developed by **Raasch, [16]** to understand uni-and bi-articular muscle coordination of maximum-speed startup pedaling.

He generated a forward simulation of muscle coordination of pedaling, compatible with kinematic, kinetic and EMG measurements, to understand the fundamental muscle coordination principles associated with the delivery of energy to the crank. Maximum-speed pedaling was chosen to produce a simulation using optimal control and to transfer as much energy as possible from the muscles to crank subject to the specific frictional and inertial load encountered at the crank. He concludes that these alternating functional muscle groups might represent a centrally generated primitive for not only pedaling but also other locomotors tasks.

The similar type of work is carried out by **Neptune [17]** where he tried to understand the lower extremity Neuro Muscular coordination in cycling. He tried to examine the effect of pedaling rate on coordination strategies and interpret any apparent changes between eight lower extremity muscles.

The study was done by **Neptune [18]** to determine whether muscle activation, force, stress and endurance quantities were associated with preferred pedalling rate selection from a theoretical perspective and also to verify whether any of these quantities could be used to predict the preferred pedalling rate. A forward dynamic model of cycling and optimization frameworks was developed here, and used to quantify the various specific neuromuscular quantities of interest at particular pedalling rate.

The results from these pedaling simulation indicated that all Neuro Muscular quantities were minimized at 90 RPM when summed across muscles. These results also suggest that minimizing Neuromuscular Fatigue is an important mechanism in pedaling rate selection. The results of these study showed that prediction of preferred pedaling rates might be difficult on the basis of performance measure of a single neuromuscular quantity to be used in an optimization frame work.

The results of forward dynamics of simulation were analyzed by **S.A. Kautz & R.R. Neptune [19]** to demonstrate how muscles perform external work both directly and indirectly during pedaling. Indirectly, muscles do work to accelerate the leg segments, and when the segments are decelerated, muscles transfer the associated energy to the crank to perform external work.

Muscles generate forces that redistribute segmental energy between the leg segments and the crank. They accelerate and decelerate the legs resulting in an increase and decrease of their total energy.

It is observed that during cycling, energy from the thigh and shank is transferred to the crank through the force applied to the pedal and external work done. Our analysis of pedaling also suggests that internal work measures will be similarly flawed in other locomotors tasks where muscles cause significant external work to be done by the deceleration of the body segments. (e.g., cross-country skling, swimming).

The purpose of the study by **D. Bibbo [20]** was to use a modeling approach in order to predict lower limb muscle force patterns during cycling with particular attention to the changes in muscular synergies due to kinematic, kinetic and physiological changes. The study will be carried on by implementing a classical inverse dynamics approach to estimate muscular force to be correlated with the electrical indicators i.e. surface Electromyography (sEMG) activity of muscular status. The model is based on kinematic and dynamic data, acquired during cycling tests by using an instrumented pedal, and on the inverse dynamic analysis.

The muscular activity provided by both the model and the sEMG envelope has been estimated along the whole test session, and the results have been compared showing a good correlation between the force behavior and the envelope of sEMG signals.

Maximum Power Output:

It is experienced that human powered vehicles are more effective aerodynamically than the standard cycling position. It is difficult to reduce the aerodynamic drag beyond certain limit. The most logical area to explore would be the human engine which powers the vehicle, and how the individual should be sealed, configured, oriented, and/or positioned to maximize power production and cycling performance.

The large number of biomechanical and external mechanical factors was studied by **Too [21]** to measure the performance in human powered vehicles (HPV). Researchers of HPV’s focused on to minimized resistive forces (friction, drag) as well as to maximized propulsive forces. The maximization of propulsive forces through vehicle design is not often understood because of a complex interaction between internal biomechanical factors (muscle force/torque/power production) and external mechanical factors (e.g., seat-to-pedal distance, crank arm length, seat-tube angle, backrest angle, chain wheel size).

The purpose of this work 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.

It should be noted that the optimum parameter (e.g. crank arm length and/or seat-to-pedal distance) to maximize power for one cyclist (determined from trial and error) might not be optimum for another, especially when cyclists have different anthropometrical characteristics (in height, leg length, thigh/leg length ratio, etc).

The changes in pedal crank arm length on power production in recumbent cycle ergometry were studied by **Danny Too [22]**.

All subjects were tested in each of the five crank arm length conditions and calculated the peak power, mean power and fatigue index for each of crack length. It appears that changes in pedal crank arm length by 35 mm can significantly affect cycling performance, as evidenced by changes in peak and mean power, which is attributed to changes in joint kinematics

Therefore, if the goal in recumbent cycle ergometry is (1) maximizing power production in the shortest period of time , the 110 mm crank arm length is accepted; (2) development of the largest mean power over a 30 second interval , the 180 mm crank arm length is accepted; (3) optimizing peak and mean power propulsion, this would require a compromise between the 110 and 180 mm crank arm length, and the 145 mm crank arm length would be suggested and recommended.

It was concluded that the optimal crank arm length in the development of faster and more effective human powered vehicles, or to maximize performance in recumbent cycle ergometry, will be dependent on the goal of the activity.

A similar type of work is again carried by **Inbar [23]** to find out whether optimal crank length for maximizing short term output was different than that commonly in use on most kinds of bicycle in general and cycle ergometers in particular.

The existing bicycle drive mechanism which is a lever-crank inversion of a four bar chain was modified by using for QRR-1 and studied by **Modak [24]**. It is very interestingly observed that the suggested new mechanism QRR-1 is advantageous for rider in the age group 21-22 as compared to existing drive as such-

1)A rider in the age group 21-22 years, with 165cm height and slim stature is highly compatible with Q.R.R. = 1 drive from the point of view of getting more bicycle speed and from the point of view of saving energy of rider.

2) At no load and maximum load Q.R.R. =1 drive in general is expected to give more bicycle speed than Existing drive.

3) For riders with 21-22 years age group, slim stature the energy input saving goes on increasing with the load.

The mechanical efficiency of cycling with the effect of new pedal-crank prototype (PP) and by using a standard pedal-crank system (SP) was investigated by **Zamparo [27]** during an incremental test on a stationary cycle ergometer in the same experimental conditions and with the same subjects.

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. This variability was expected to lead to a decrease in the energy requirement of cycling since, for any given thrust, the torque exerted by the pushing leg is increased while the counter-torque exerted by the contra-lateral one is decreased.

Even if the improvements in the efficiency of cycling observed in this study were rather small (about 2%) and apparent only at higher load tested,

-they indeed show that the transmission efficiency of cycling could be further improved by means of a pedal-crank of variable length.

- it can be calculated that that an athlete riding a bicycle equipped with the patented pedal-crank could improve his cycling performance.

Miller [30] proposed a technique for generating a chain drive capable of allowing a desired varying angular velocity function on the driving shaft. While constant angular velocity is maintained at driven shaft .The variable ratio bicycle drive is hardly a new concept. The goal of the design of these devices intended to extract the maximum short term power from a bicycle rider. They may be intended to allow the rider’s muscles to operate at peak physiological efficiency, thereby maximizing power output within the riders aerobic (long-term working) capacity. They may be designed to help the rider maintain a high driving moment while the cycle moves at low speed. Finally they may be designed to impart some desired motion on a muscle or group of muscles in the leg for biomechanical research or physical-training purposes. The synthesized drive train shows a theoretical 12.6 percent increase in delivered power.

In order to overcome the limitations of the existing mechanism, the following modification to the existing mechanism was suggested by **Modak [31],** (i) QRR-1(ii) reciprocating pedal mechanism (iii) double lever inversion (iv) elliptical sprocket. In comparing the experimental results, experimenter finds the advantages of various mechanisms compared to existing mechanism by plotting and comparing the area under the torque curve.

In the normal operation of bicycle, it must be realized that all the energy to the bicycle is supplied by the rider. Hence in the existing bicycle large force is applied for small time and in modifications smaller force is applied for larger time. Thus, the modification will be able to make the bicycle speedier and suitable for steeper gradients. In his further work [32], author discusses the methodology of experimentation to verify the theoretical performance of the suggested drives.

The purpose of the study by **Rankin [34]** was to improve the cycling performance (i.e. maximal power output) by optimizing the chainring shape to maximize average crank power during isokinetic pedaling conditions. 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 .

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

While the focus of this study was on optimizing the chainring shape at the preferred pedaling rate of 90 rpm, the optimization framework was also used to determine if the optimal chainring shape varies with pedaling rate.

Optimization Analysis

During study of optimization, optimal pedalling rate and optimal pedal speed were defined as those values at which maximum power occurred.

The biomechanics of bicycle pedaling was studied by **Red Field [10]** to predict optimal pedal forces. For this, analysis of variance was used to determine whether crank length significantly affected maximum cycling power, optimal pedalling rate, or optimal pedal speed.

This work presents a biomechanical analysis of the lower limb while cycling using some of the lower limb modeling techniques, optimization strategies and evaluation methods. Analytic dynamic system model of lower limb is useful for both identifying and examining causal factors influencing performance.

The bicycle-rider system is modeled as a planar five-bar linkage with pedal forces and pedal dynamics as input. They have shown that in the pedalling activity the lower limb muscle stresses may be determined with good accuracy directly from the joint moments developed about the hip, knee and ankle

The various variables was studied by **Hiroko Gonzalez [12]** to extend the optimization analysis to three, four and five variables, in order to understand the relation between all biomechanical variables and the intersegmental moments. Relying on a biomechanical model of the lower limb which treats the leg-bicycle system as a five-bar linkage constrained to plane motion, cost function derived from the joint moments developed during cycling is computed. At constant average power of 200W, the effect of five variables on the cost function is studied. The five variables are pedaling rate, crank arm length, seat tube angle, seat height, and longitudinal foot position on the pedal

The objective of work is to examine the sensitivities of each of the five variables, to simplify the optimization problems by reducing the numbers of variables if any are non-interacting, to solve the multivariable optimization problem where all five variables are considered simultaneously. The solution will determine if a set of variable values exists such that the joint moment-based cost function is minimized while all variable values are within practical limits.

A sensitivity analysis of each of the five variables shows that pedaling rate is the most sensitive, followed by the crank arm length, seat tube angle, seat height, and longitudinal foot position on the pedal (the least sensitive). Based on Powell’s method, a multivariable optimization search is made for the combination of variable values which minimize the cost function.

The effect of anthropometric parameter variations is also examined and these variations influence the results significantly. The optimal crank arm length, seat height, and longitudinal foot position on the pedal increase at the size of rider increases whereas the optimal cadence and seat tube angle decrease as the rider’s size increases. The dependence of optimization results on anthropometric parameters emphasizes the importance of tailoring bicycle equipment to the anthropometry of the individual.

The various interaction of number of variables which affect the Cycling performance inhuman powered vehicles was studied by **Danny Too [14]** which includes environment, mechanical and human factors. Engineers have generally focused on the design and development of faster, more efficient human powered vehicles based on minimizing aerodynamic drag, neglecting the human component. On the other hand, kinesiologists have examined cycling performance from a human perspective, but have been constrained by the structure of a standard bicycle.

There are a large number of factors affecting cycling performance: environmental factors (e.g. aerodynamic drag, rolling resistance, hills, head and tail winds, altitude); mechanical factors (e.g. wheel size and inertial properties, friction in power transmission, elliptical chain wheels and cams); biomechanical and physiological factors (e.g. muscle length, joint angle, muscle moment arm length, type of lever, speed and type of contraction, fibre type and arrangement, recruitment pattern, etc.). There are large numbers of factors affecting cycling performance.

To maximize and/or optimize cycling performance requires a definition of performance, the criterion for performance and the constraints imposed upon it. If the criterion is development of an ultimate human-powered vehicle to establish unprecedented speed and/or distance records on land, air and/or sea, then information must be obtained regarding the interaction of environmental factors with mechanical and human factors. This would involve the design and development of a human powered vehicle to not only account for aerodynamic and/or hydrodynamic drag, but also to seat and position an individual in an orientation and configuration that would optimize interaction of the various neurological, biomechanical and physiological variables related to power, work, energy and efficiency. Further interdisciplinary research needs to be undertaken before final solutions to these issues can be obtained.

The objective of the study by **Hull [25]** was to extend the works of Redfield and Hull [9] by undertaking a bivariate optimization where both pedaling rate and crank arm length are varied simultaneously. It is also examined quantitatively how optimized pedaling rate and crank arm length vary with power output.

Relying on a biomechanical model of the lower limb, a cost function derived from the joint moments developed during cycling is computed. Anthropometric parameter variations influence the results significantly. In general it is found that the cost function minimum for tall people occurs at longer crank arm lengths and lower pedaling rates than the length and rate for short people. Recognizing that the anthropometry of the rider will affect optimization results, and to assess the impact on the results of different size riders.

They concluded that since optimization results were not significantly different for the two cost functions, it is advantageous to use the moment-based cost function in future analyses since it is simpler to compare. Broaching the subject of multivariable optimization, they completed a two –variable optimization of pedalling rate and crank angle length using the joint moment –based cost function. The sensitivity of the cost function to both variables was significant and the variables were interacting. The significance of the remaining variables to the cycling biomechanics optimization problem remains unknown.

The effect of cycle crank length was studied by **Martin [26]** to investigate its effect on maximum cycling power, optimal pedaling rate, and optimal pedal speed, and to determine the optimal crank length for maximal power production.

He suggests that pedal speed (which constrains muscle shortening velocity) and pedaling rate (which affects muscle excitation state) exert distinct effects that influence muscular power during cycling. Even though maximum cycling power was significantly affected by crank length, use of the standard 170-mm length cranks should not substantially compromise maximum power in most adults.

Cycle crank lengths that varied by 83% elicited a mere 4% variation in maximum cycling power. Optimal pedaling rate decreased with increasing crank length, whereas optimal pedal speed increased with increasing crank length. The differing optimal conditions for these two rate terms suggest that pedal speed (which represents muscle shortening velocity) and pedaling rate (which influences muscle excitation) exert distinct effects that limit muscular power during cycling.

Hansen [28] 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.

Interestingly, the change in crank inertial load affected the freely chosen pedal rate as much as the 100W increase in work rate. Higher crank inertial load resulted in higher peak crank torque at a constant pedal rate that via increased mechanoreceptor stimulation possibly induced an increase in perceived exertion. This in turn possibly caused the subjects to increase their pedal rate, since both mean and peak crank torque was thereby reduced.However, an increase in pedal rate may reduce the gross efficiency and subsequently the long duration performance.It is therefore important to account for crank inertial load when investigating cycling performance.

The 3 ^4 factorial design of experimentation was designed by **Cho[33]** to measure the optimal pedaling rates for given power output levels as well as design the optimal number of gears and the corresponding gear ratios.

A bicycle gear system is frequently designed without ergonomic expertise in terms of performance and efficiency. This study provides guidelines, design specifications, and performance measures to design an efficient bicycle gear system. This study also contributes valuable finding regarding the optimal performance during bicycle riding, thereby facilitating the efficiency and effectiveness of human exercise using a bicycle.

A preliminary user survey revealed that the average utilization of multi-speed gear system is less than 40%. Thus, with respect to human performance and power efficiency, current design of gear system is inefficient and hard to use because of the many number of unnecessary shifts.

The main function of multi-speed gear system can be considered to provide the shifting mechanism that a human can select his/her own combination of pedaling force and rate under certain degree of power output. Therefore, the optimal gear ratio of a bicycle can be defined as the most physiologically efficient combination of pedaling force and pedaling rate. Above studies used various physiological measures such as oxygen consumption, heart rate, and EMG as well as riding performance.

Analysis of literature:

The work done by various researchers have been analyzed on below parameters-

I] Energy Expended by Man:

In the literature different methods of measurement of power utilized by a peddler during pedaling are reported. For comparison of input and output energy, most commonly use method is measurement of oxygen consumed during the time exercise. Modak and Ketkar (32) Croisent and Boileau (6), Seabury et al (1), Patterson et al (5) have used the same method. Croisent and Boileau (6) Measured heart rate, temperature. Patterson et al (5) have recorded the ECG, heart rate. Manker (35) measured increase in pulse rate for the same.

II] Actual field test necessity of experimentation:

On road, driving conditions of Cycle- Rickshaw are different than the assumed theoretical conditions. Road resistance and therefore rear wheel torque varies continuously according to the condition of the road surface and gradient. Also the resisting toque is much high at the starting than in running condition due to high inertia of the system.

A cycle-rickshaw puller applies the required force at the pedal-crank such that necessary torque is produced at the crankshaft to overcome the road resistance at the rear wheels. Pedal forces are much high starting from the rest and climbing the gradient as compared to the plain road driving. To further confirm the results of the analysis, physiological response i.e. pulse of the cycle-rickshaw puller at the time of the driving the rickshaw is recorded. The purpose of the experimentation on the road track is to compare the requirement of human energy expenditure of all cycle-rickshaw model as per 3^3 factorial design of experimentation and to determine optimum wheel diameter and speed ratio

III] Various method of analysis used earlier

The analysis of variance [26] was used to determine whether crank length significantly affected maximum cycling power, optimal pedalling rate, or optimal pedal speed. If significant main effect of crank length were detected, the Bonferoni post hoc procedure was used to determine which crank lengths differd.Second order polynomial regression analysis was performed to determine the optimal crank length for maximum power.

Five male undergraduate students participated in this study [33]. To obtain the optimal gear ratio, three different power output levels and four different pedaling rates were used as independent variables. Heart rate, ratings of perceived exertion and electromyogram of quadriceps femoris were measured at three different power output levels. The experimental design was 3 by 4 factorial design without repetition. Ergometer and pulse meter were used to provide a constant power level and measure the heart level. According to the results of analysis of variance (ANOVA), power output and pedaling rate significantly influence heart rate and RPE

IV] Necessity of Study of speed ratio and wheel diameter

Energy to diver the cycle-rickshaw is provided by human being who works as an engine. The muscle power, basically those of buttocks, upper leg and lower leg transmitted to the pedal-cranks, which ultimately drive the rear wheels. The cracking mechanism is used for conversion of muscle power into the useful torque. Rickshaw puller propels the vehicle at his choice of speed and accordingly adjusts the pedal force and repetitive rhythm of muscles. To increase the power conversion of the cycle-Rickshaw puller and therefore to minimize the energy expenditure of rickshaw puller while pulling heavy load measuring approximately 250 kg, so it is felt necessary to optimize wheel diameter and speed ratio of cycle-rickshaw.

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