Performance Evaluation of Leaning Reverse Trike

Jawwad A. K. Lodhi
M-tech Student (M.E.D)
Department of Mechanical Engineering
Anjuman College of Engineering & Technology, Nagpur
Maharashtra

Nafees P. Khan
Assistant Professor
Department of Mechanical Engineering
Anjuman College of Engineering & Technology, Nagpur
Maharashtra

Abstract

This paper presents a unique experiment based on a very small and emerging sector of automotive industry, i.e. reverse Trikes or three wheeled vehicles. A REVERSE TRIKE is a vehicle which has two wheels up front and one in the back. A reverse trike is basically a vehicle having two wheels in the front and one on rear side. Most cars have the engine driving the rear wheel and leave steering to the front ones. Some are eco-friendly human powered vehicle with a compounded electric drive system and some are powered by I.C. Engines. The incidence of accidental deaths has shown an increasing trend during the period 2003-2012 with an increase of 51.8% in the year 2012 as compared to 2002; Because of the fact that that these vehicles are very safe to drive and will be very less to become accident prone these three wheelers could be the future of the automotive sector, In the early 20th century three-wheelers gained in popularity as low-cost, lightweight vehicle that is, until about the late 1920s, when cars generally started going more along the four-wheel track. The main aim of this research paper is to evaluate the performance of a three wheeled vehicle based on leaning mechanism and to develop a transition mechanism namely tilt lock system which can transform the leaning vehicle into non-leaning and vice versa according to the requirement. The conceptual design of the project model is based on the study of several literatures related to reverse trike. The mechanisms used for available reverse trikes are very costly and electronics based. So we want to design the mechanism which can overcome the drawbacks of the existing design of a conventional vehicle and also it should take benefit of the three-wheeled transportation and it should also contain the features of an electric vehicle because it is environment friendly. Now for making the system cost effective we have incorporated mechanical leaning system in our design so as eliminate the costly electronic components. The main advantage of this mechanism is that it makes the vehicle more stable during high speed turns so that even a reverse trike can take a turn like a sports bike by leaning to its side. The results of experimental testing are presented to illustrate the real balancing performance of the combined steering and tilting approach used for the Leaning reverse trike that is very economical and fairly simple to drive. In this research it is found that the performance, handling and safety of the Leaning Reverse Trike are much better than any other commercially available three wheelers. The actual fabricated prototype is named as "KLISI"

Keywords: Three Wheeled vehicle, Leaning Reverse Trike, Tadpole Design, Delta Design

I. INTRODUCTION

A trike is a three wheeled vehicle, having either one wheel in the front and two at the rear for power, or two in the front for steering, and one in the rear for power, or any other types of layouts. Due to the handling superiority of this vehicle, an increasingly popular form is the front-steering “tadpole” or “reverse trike” The idea of smaller, energy efficient vehicles as personal commuters seems to naturally introduce the three wheeled platform. Opinions normally run either strongly in favor of or strongly against the three wheel layout. Advocates point to a lower manufacturing costs, mechanically simplified chassis, and superior handling characteristics. Having one wheel up front and two in the back is known as the delta configuration. Opponents decry the three-wheeler’s propensity to overturn. Both opinions have merit. Trikes are lighter and economic to manufacture. When designed poorly a three wheel platform is the less forgiving layout. But when designed correctly, a three wheel car can light new fires of enthusiasm under tired and routine driving experiences.

Designing to the three wheeler's inherent characteristics can produce a high performance machine that will out corner many four wheelers.
Fig. 1.1: concept of trike prototype

And today's tilting three wheelers, vehicles that lean into turns like motorcycles, point the way to a new category of personal transportation products of much lower mass, far greater fuel economy, and superior cornering power.

II. LITERATURE REVIEW

A. Review on tadpole design – issues & challenges [1]

The three wheel configuration allows the two front wheels to create the wide round surface of the vehicle. The single rear wheel allows the vehicle to taper at the back. Having one less wheel also increases fuel efficiency because of decreased rolling resistance. The disadvantage of a rear drive, non-tilting three wheel configuration is instability – the car will tip over in a turn before it will slide, unless the centre of mass is much closer to the ground or the wheelbase is much wider than a similar four wheel vehicle. To improve stability some three wheelers are designed as tilting three wheelers so that they lean while cornering like a motorcyclist would do. The tilt may be controlled manually or by computer. Electric three-wheelers often lower the center of gravity by placing the heavy battery pack at the base of the vehicle. This conclusion is easily understandable if a 3-Wheeler with two front wheels is considered. If the center of gravity of the vehicle occupants assembly is sufficiently low to be under the pyramid, the vehicle will not roll sideways in a curve and will not tip backward when accelerating or tip forward when braking. [1]

B. Accidental Deaths in India. [2]

The incidence of accidental deaths has shown an increasing trend during the period 2003 -2012 with an increase of 51.8% in the year 2012 as compared to 2002; however 0.2% decreases was observed in 2003 over previous year 2002. The population growth during the period 2003-2012 was 13.6% whereas the increase in the rate of accidental deaths during the same period was 34.2%. A total of 1,18,533 males and 20,205 females totaling 1,39,091 persons were killed during the year 2012. A total of 32,318 persons (23.2%) were died due to accidents of ‘two-wheelers’, ‘truck/lorry’ accounted for 19.2% (26,678 persons), ‘cars’ accounted for 10.1% (14,110 persons) and ‘buses’ accounted for 9.4% (13,076 persons) of accidental deaths during the year 2012. [2]

C. Steady-state steering of a tilting three-wheeled vehicle. [3]

The CLEVER vehicle is an enclosed, narrow track tilting vehicle developed for urban environments. Its narrow track necessitates a tilting system to allow for higher lateral accelerations without the risk of rolling over. Car-like controls and driver characteristics were deemed essential for user acceptance. The investigation of cornering dynamics reveal that a basic 1F1T vehicle oversteers considerably compared to the ideal Ackermann response due to the cornering effort generated by a highly cambered front wheel. Achieving a steer response close to the ideal by altering the tyre characteristics or reducing the tilt of the front unit to reduce the camber thrust of the front tyre are not acceptable solutions. Thus, an additional steering mechanism is essential for this vehicle configuration. The kinematics associated with a 1F1T tilting vehicle was assessed through the use of a kinematic vehicle model. [3]

D. Stability Analysis of a Three-Wheeled Motorcycle. [4]

In this work the modal analysis of a three-wheeled tilting motorcycle is presented. This new kind of vehicle has two front wheels and a single rear wheel, but is driven like a common motorcycle. In order to study the stability of the system in straight running,
two models have been developed: a simplified motorcycle model, with locked suspensions and rigid and thin tires and a more accurate model having 14 degrees of freedom, in which the stiffness and damping of suspensions and the radial stiffness of tires have been taken into account. In both models the frame has been considered as rigid and the driver was assumed to be fixed to the frame. A linear model with transient behavior has been employed for describing the tire behavior. Analyzed and discussed in this work; Piaggio MP3, a novel tilting vehicle, which has a front system with two steering wheels, was taken as a reference for this study. Two different models of the vehicle have been set up, by taking or not into account the compliance of suspensions and tires. In order to compare the stability analysis of such vehicle with a similar two wheeler, a model for this latter vehicle has been also developed. The obtained results have shown how in straight running the three wheeled motorcycle has a higher stability of the weave mode if compared to the two wheelers; indeed it has been found stable in the whole examined speed range. [4]

**E. Status of the vehicular pollution control programme in India.** [5]

The rapid urbanization in India has also resulted in a tremendous increase the number of motor vehicles. The vehicle fleets have even doubled in some cities in the last one decade. This increased mobility, however, come with a high price. As the number of vehicles continues to grow and the consequent congestion increases, vehicles are now becoming the main source of air pollution in urban India. Although, the air quality can be improved through a combination of technical and non-technical measures, legislative reforms, institutional approaches and market-based instruments, there are certain unique challenges which the country has to face in tackling the problem of urban air pollution. These include, the transport features which are different from the developed countries particularly in terms of the types of vehicles commonly used, the manner in which the road network is operated and sharing of the limited space by pedestrians and non-motorized modes with modern vehicles in Indian cities. [5]

**F. Brudeli 654L.** [6]

The Brudeli 654L is a way of getting closer to that dream. The footboards stay parallel to the ground, while the rest of the vehicle, including the two front wheels, leans at an angle of up to 45 degrees. The two wheels in front also provide a shorter brake length. This is both about fun and safety. The design of the new model was executed by Atle Stubberud of the company ‘Soon Design’ (www.soondesign.com). Atle Stubberud was also the key designer for the concept model from 2005. “This really is a dream project for a transportation designer. Nearly like a student project where you could start with a completely open mind. I have been involved since the idea was first formulated in 2001.” [6]

**III. DESIGN**

A Reverse Trike has the advantages of both the type of vehicle that is cars and bikes. If we make these vehicles lean into corners it makes it a perfect, virtual single track vehicle and even though having three wheels it can be driven like a motorcycle, and the third extra wheel gives the vehicle more traction to make it safe even at high speeds but these incredible vehicles are divided into two categories namely leaning reverse trikes and non-leaning reverse trike. On the one side when we consider the non-leaning vehicle, they are stable like a car and are best at low speed and in traffic conditions but have to struggle with centrifugal force at high speed during cornering (taking a turn). On the other side if we consider a leaning reverse trike they are very good at high speeds and counteracts the centrifugal force by their leaning action but are terrible in the traffic and at low speeds as the driver have to put there foot down to support the vehicle. The objective to carry out this project is to develop a transition mechanism which can transform the leaning vehicle into non-leaning and vice versa according to the requirement so that it can be driven as both leaning and non-leaning vehicle which will make it a perfect vehicle for Indian road conditions.

**A. Frame:**

As a prototype to evaluate the performance of leaning reverse trike, we built a three wheeled leaning vehicle. The vehicle we built has three wheels that all lean together with the vehicle body. The single rear drive wheel has an electric BLDC motor to drive the vehicle. We chose this configuration because it simplified the rear chassis and drive train design. The drive train was custom built to match the power and torque need of the vehicle, is a single unit that was simply bolted into place. This meant that we only needed to build the frame to match the required vehicle subsystems. We used the front wheels from sports bikes and built custom forks to accommodate the wheels and match the front chassis.
A frame is a basic supporting structure of the vehicle which supports all the other subsystems of the vehicle so it should be strong enough to withstand the rigorous forces that will act on it but at the same time it should be as light in weight as possible to increase the efficiency. The entire body weight acts on the frame which is then transferred to the wheels through the front and rear suspension members the support reactions from the wheel is then obtained.

As the design of the frame Mark-43 was made using cad software the digital specifications are as follows.

Table 3.1

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Particular</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Height of C.G.</td>
<td>443 mm</td>
</tr>
<tr>
<td>2</td>
<td>Distance from front</td>
<td>938 mm</td>
</tr>
<tr>
<td>3</td>
<td>Total volume</td>
<td>0.006 m³</td>
</tr>
<tr>
<td>4</td>
<td>Length</td>
<td>2183 mm</td>
</tr>
<tr>
<td>5</td>
<td>Height</td>
<td>1426 mm</td>
</tr>
<tr>
<td>6</td>
<td>Width</td>
<td>626 mm</td>
</tr>
</tbody>
</table>

As we know that,

\[ \sigma_b = \frac{M}{Z} \]

\( \sigma_b \): bending stress

\( Z \): section modulus for hollow pipe

\[ Z = \frac{\pi}{32} \frac{d_o^4 - d_i^4}{d_o} \]

\( Z = \frac{\pi}{32} \frac{32^4 - 28^4}{32} \)

\( Z = 1331.24 \text{ mm}^3 \)

Therefore,

\[ \sigma_b = \frac{238350}{1331.24} \]

\( \sigma_b = 179.04 \text{ N/mm}^2 \)

From the design data book, the Maximum allowable bending stress in our material is 560 Mpa > \( \sigma_b \) induced.
Hence, the frame can take more than three times its design weight i.e. around 900 Kg. It was further verified from the literature survey that these type of frame can sustain very high loads without big damage.

B. Front A-arms:

A-Arms are the main components of the suspension geometry and are made with the same material with which the frame is made i.e. SAE 4130 alloy steel. In our design the diameter of A-arms is 1.25 inches same as the diameter of the tube for the frame here we wanted to make the A-arms as short in length as possible as bigger A-arms will make a very wide vehicle. The control arms will attach to the frame using a deep groove ball bearing and M12 high tension bolts. After reviewing various different vehicles and reverse trikes we have landed on the design shown below.

C. Wheel hub:

Wheel hub is the part which connects the wheels with the control A-arms, it provides the wheels to be mounted on to them and on the other hand it is connected to the upper and lower control arms with the help of ball joint called rod end bearings. Hub is an important part in our design, as all the important alignment angles are given to the vehicle through the hub. The position of upper and lower mounting points for the rod end bearings on the hub determines the value of King pin inclination which is very important as it directly affects the handling and performance of the trike.

D. Rear swing arm:

For the driving wheels we are using an 18inch alloy wheel from an old bike so the drive mechanism remains the same that is the simple chain drive which will be driven by the transmission shaft for the electric drive system, but to keep the wheel base small we shorten the swing arm. So we decided to go for custom made swing arm and made one right from scratch.

The figure below shows the cad model of the swing arm.

E. Central suspension linkage:

The central link has been specifically incorporated in the design of this leaning reverse trike “Klisi”. This link will actually allow the whole vehicle to lean in either of the directions during turning. Both the suspensions upper mounts are attached to this link instead of the rigid frame as in case of the traditional design of double wishbone type suspension system of the cars. This is actually the main link which separates the leaning vehicle from the non-leaning ones the final dimensions of this link is purely based upon the calculations of the leaning mechanism and simulation of the whole assemble (done using CATIA V5 vr19).

F. Tilt locks mechanism:

We have seen that the present available vehicles in the market, has complicated electronic computer systems that controls and actuates the leaning of the vehicle during a turn and also make the vehicle stand still when it is stopped but all this is achieved by a microprocessors and electronic sensors which in turn signals the hydraulic actuators to work accordingly this is good but this increases the cost of the vehicle and that is why these vehicles are not seen in India.
In our prototype we want to transform the leaning vehicle into non--leaning and non-tilting vehicle to leaning as and when required during the ride, for achieving this we will use disc brake and caliper assembly which is also used by the famous Piaggio Mp3 but we will control it by using manual foot pedal. The fig. above shows the tilt lock of Piaggio Mp3 and the cad model of our design Klisi. For the actuation of the tilt lock we are going to use a standard available disc brake pedal assembly from Bajaj.

The amount of the locking force that can be applied by this system, can be estimated in the following manner:

We know that the pedal is class 1 lever and for the pedal ratio we have a ratio of 3.88:1

\[ \frac{W}{P} = \frac{l_2}{l_1} \]

\[ W = \frac{P \times l_2}{l_1} \]

We know that a normal human being can easily apply a force of 350N to 579N. So consider a force of 400N is applied on the pedal

We have  
\[ P = 400N \]
\[ l_1 = 45mm \]
\[ l_2 = 175 mm \]

\[ W = \frac{400 \times 175}{45} \]
\[ W = 1555.56 N \]

This is the force which will be exerted on the piston of the master cylinder but we need the force which will be exerted by the brake pads to grab hold the metal disc. Now we have

\[ P = \frac{F}{A} \]

Where \( P \) is the pressure
\( F \) is the force applied
\( A \) is the area

We have the area of the master cylinder as \( A_1 \) i.e. 176 mm\(^2\)
And the area of the pistons in the caliper as \( A_2 \) i.e. 981 mm\(^2\) as there are two pistons in the caliper

Equation 4.22 implies

\[ P = \frac{1555.56}{176} \]
\[ P = 8.83 N/mm^2 \]

But the ratio of the area of the pistons in master cylinder and caliper is 5.57, therefore

\[ P = 8.83 \times 5.57 \]
\[ P = 49.18 N/mm^2 \]

Now for the force applied by the caliper pads will be

\[ F = P \times A_2 \]
\[ F = 49.18 \times 981 \]
\[ F = 48245.6 N \]

This is the force which will be exerted on the tilt lock disc by the caliper pads

IV. RESULTS AND DISCUSSION

The results of experimental testing are presented to illustrate the real balancing performance of the combined steering and tilting approach used for the Leaning reverse trike.

The results of implementing mechanical leaning system to a reverse trike are as follows

- It was found that the maximum leaning angle in each direction is 36 degree from the vertical. This allows the rider to take turns confidently without having the fear of falling or skidding
- The maximum speed of our fabricated prototype Klisi is found to be 51 Km/h which is greater than any other electric vehicle available in the market today.
- The actual turning radius of our fabricated model Klisi is found to be 4.2 meters which is which is smaller than the turning radius of CAN-AM Spyder (which is a three wheeled vehicle) and most of the small cars. The turning radius does not
seems to be very small but with the leaning ability if our prototype we can confidently take much tight turns as compared to other vehicles
- The costly electronic components of the traditional design are replaced by the mechanical linkages so the cost of whole vehicle is effectively reduced
- As the vehicle is developed in category of leaning reverse trike and combines the advantages of car and bike it is very much comfortable to drive
- Due to leaning the center of gravity of the vehicle is always balanced and the resultant forces and their reactions are lined up which increases the life of the mechanical components.
- The braking distance of our vehicle is found out to be 19.73 meters
- As this mechanism contains a tilt lock it can be easily ridden both in high speed as well as low speeds and that too very easily.
- At high speeds there is negligible speed wobble
- As the vehicle is an electric vehicle its prime mover that is an electric motor is 90% to 95% efficient so we get 95% of the power of the batteries in the road wheels

V. CONCLUSION

We have successfully designed and fabricated a prototype model of Leaning Reverse Trike (i.e. Klisi), which combined the advantages of reverse trike design, leaning mechanism & electric drive system. From the study we know that the most of the accidents take place due to skidding of the front wheel in the sudden braking condition while taking a turn, our design has two wheels in the front and also the ability to lean, which prevents the vehicle from skidding and losing control of the vehicle on road. Klisi is eco friendly as it is an electric vehicle. It is also very economical and fairly simple to drive. Thus we can conclude that the performance, handling and safety of the Leaning Reverse Trike are much better than any other commercially available three wheelers.

ACKNOWLEDGMENT

With profound feeling of immense gratitude and affection, I would like to thank my guides Prof. M. SHAKEBUDDIN, Professor, Department of Mechanical Engineering and Prof. NAFEES P. KHAN, Professor, Department of Mechanical Engineering for his continuous support, motivation, enthusiasm and guidance. His encouragement, supervision with constructive criticism and confidence enabled me to complete this research. I also wish to extend my reverence to him for providing necessary facilities to complete my research.

REFERENCES

[5] Central Pollution Control Board “status of the vehicular pollution control program in India” Ministry of Environment & Forests, Govt. of India, East Arjun Nagar, Delhi – 110 032.