Design and Study of Single Lateral Pivot Folding Trike

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Abstract:- Foldable light electric vehicles are the next phase of future sustainable transportation. Tricycles being one of the types for different age groups to ride, an electric tricycle is used as a design medium for including the foldability feature. The influence of foldability of bicycles and types of mechanisms of folding are studied and similar is applied at a different position than the common frame joints. Foldable position, space reducing characteristics and strength of the frame at the removable junction were measured. ANSYS software was used for the determining the stresses and deformation and analysed the extent of safe design. Hence, a satisfactory type of foldable tricycle was proposed for encouraging its benefits into future economic transportation.

***Keywords**:- Foldable; Electric Vehicles; Tricycles; Mechanisms; Frame Joints; Light Weight; Transportation*

I. INTRODUCTION

The other side of the transportation phase being the environmentally friendly urban transportation, the attention has been shifted from the automobiles to bicycles and tricycles. However, urban living environment in few developing countries such as apartments and public transportation facilities negatively affects carrying and storing bicycles. Accordingly, the need of foldable bicycles for the easy handling by reducing size is markedly increased [1]. Meanwhile, a high-priority requirement for urban bicycles is not their riding performance but their availability in compact sizes, which can be achieved by incorporating a feature in their design that facilitates them to be folded into portable sizes. By minimizing their volume, bicycles are carried on trains, buses, or any other mode of public transportation and also stored in narrow residential and office places [2]. The feature of folding is possible by means of a foldable joint. This joint has to rotate about an axis. The orientation of axis decides the offset distance between the wheels. There are various folding mechanism depending on the number, position and orientation of the pivot axis applied on the frame. These folding mechanisms affect the usability in the folding course as well as the dimension of bicycle when it is folded. There is a trade-off relation between the size reduction and the folding usability. Single pivot type is mostly used in the market. The folding mechanism using a single pivot can be divided into two kinds, depending on whether the direction of the pivot axis is horizontal or vertical.

First, the vertical axis folding mechanism to fold the frame to the lateral direction has been widely distributed to the market as of now. On the other hand, the lateral axis folding mechanism to swing the frame downward has not been widely used. But the comfort of folding motion at the lateral axis folding mechanism is worth to be significantly considered. When compared to the vertical axis folding where the mechanical effort is required to fold the tricycle, in lateral axis type the only work required is to release the clamp and it folds by itself due to the weight of the rear or front or both the wheels. So, the lateral pivot type foldable tricycle can be made a promising type of mobility for urban transportation. The main reason for its low application in foldability is that the dimension of folded tricycle is not compact as that of the bicycle. Also, the effect of the position of the hinge on the lateral stability of the frame is worth addressing especially for a trike with two wheels coming parallel to the third. The objective of this study is to investigate the effect of maximum load on the U bracket hinge. Predetermination of the motion of the folding with respect to the elements of the trike. Design variables which are involved in two-dimensional direction instead of considering three-dimensional direction on the pivot axis were defined. The reduction in the base area is found after folding. Additionally, the strength of the joint is analyzed and evaluated.

II. LITERATURE REVIEW

Jongryun Roh et. al. They evaluated foldable bicycles in terms of their usability. Four types of folding mechanisms were identified depending on the number of pivots and the pivot axis direction: single lateral pivot (SLP), single vertical pivot, dual lateral pivot, and combined vertical–lateral pivot (Fig. 1). Next, four bicycles one each of these four types were selected as test specimens. Ten subjects performed folding and unfolding tasks on each of these bicycles, and three-dimensional body motions and ground reaction forces were measured. The performance times for the DLP type were expected to be longer than those for the single pivot types (SLP and SVP) during the folding and unfolding procedures because in the DLP type, two hinges were to be folded one after another in sequence. On the other hand, the CVLP type, which also had two hinges, had a relatively short folding time because the two hinges could be folded simultaneously.

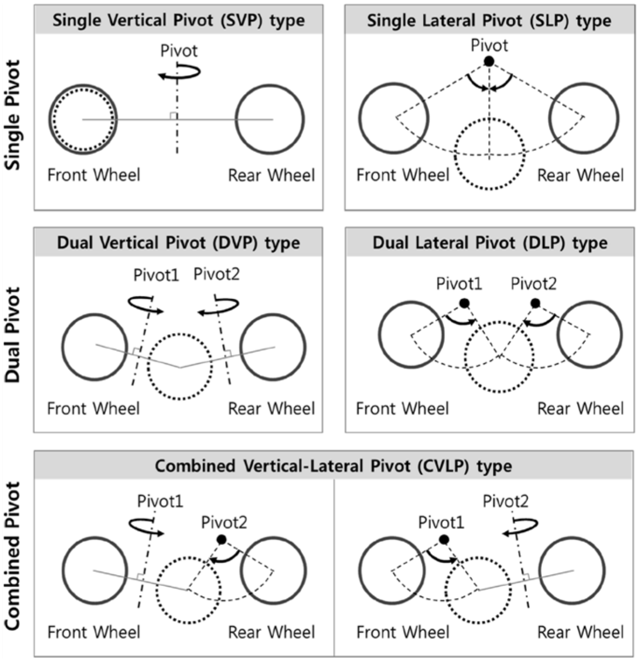

Fig 1:- Definition of Folding Mechanism Types

The maximum trunk flexion angles and maximum increments in the ground reaction force were used as governing parameters for evaluating the comfort level for each bicycle type. The SLP type provided the lowest upper body flexion and ground reaction force [1]. Jongryun Roh et. al. investigated the optimal pivot axis. The design variables are considered for three-dimensionally directional movement analysis. They studied that among the vertical axis and lateral axis single pivot folding, the comfort of folding motion at the lateral axis folding mechanism is significantly considered. Still, the use of lateral pivot bicycles is minimum due to the unparallel orientation of wheels. The kinematic simulation done showed the required optimal variables to make parallel alignment of wheels after folding the bicycle.

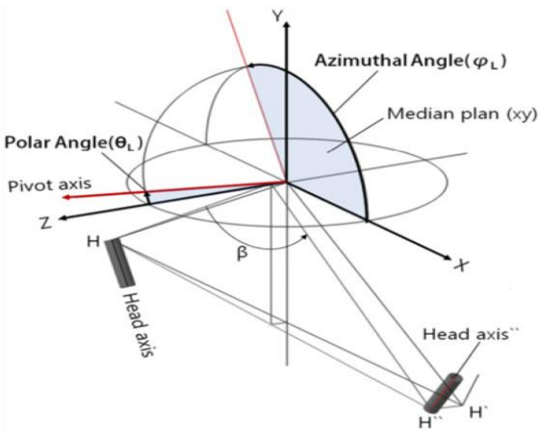

Fig 2:- Parameters of Pivot Axis at Local Coordinate System

They used CATIA V5 as a designing tool for evaluating the angles of rotation. The slanted alignment of wheels was corrected using the azimuthal angle and the polar angle (Fig. 2). The optimal azimuthal angle is found to be affected by the bicycle frame dimensions. For different cases depending upon the angles and the position of the axis gave four parallel alignment with 45, 60, 40 and 50mm offset between the parallel wheels [2].

III. DESIGN

A. Foldable Pivot Selection

There are few concepts in the market that have a parallel arrangement of the three wheels. But it is done using two foldable joints mostly both being lateral joints. As it is difficult to bring the parallel orientation in the bicycle itself using single lateral joint, the designed trike cannot use vertical joint for its low steering column height from the ground and dissimilar wheel sizes. CATIA V5 design methods are used for the design of pivot, hinge and the motion estimation of the rear triangle (Fig. 3).

Fig 3:- Dissimilar Locations of Joint and Axis of Folding on the Designed Trike

The frame contains two tubes one holding the seat rod and other having the pivot. For such designs, installing the frame joint would be so costly for the diameters more than 50mm. Unlike all other frame joints the axis of fold and the pivot can be placed at different locations and can obtain similar results.

B. Foldable Joint

The spring joint usually with a nut and bolt fixture is replaced with a quick release clamp. The quick release is made of light Al 6061 body with stainless steel bolt of 6mm dia. The path of motion of the spring when removed is checked and the slot is cut tangential to the 10mm diameter hole in the U-bracket (Fig. 4). The U- bracket is also made of stainless steel material as that of the bolt.

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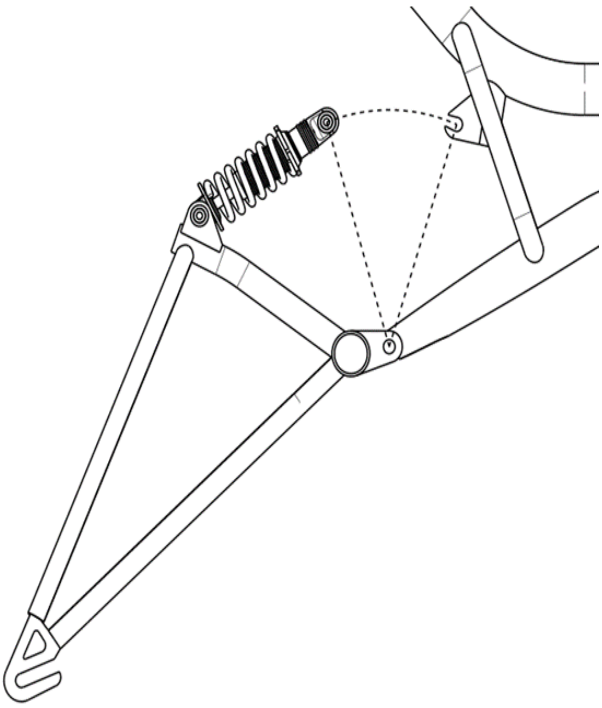

Fig 4:- Tangential Cut U-bracket with Reference to the Path of Spring Movement

Standard U-brackets are available that have a good strength. The bracket used here is cut tangentially such that the direction of force exerted by the spring is opposite to the cut. If not, the joint would release itself when load is applied. The strength of the U-bracket is more than the that of the material used for the frame i.e., AISI 1020 (Table. 3).

Material	Young's modulus Gpa	Yield strength Mpa	Tensile strength Mpa	Density Kg/m3
AISI 1020	210	200	380	7870
Stainless steel	193	207	586	7750

Table 1:- Mechanical Properties of Material

C. Load Estimation on Joint

The load acting on the frame is considered to be a maximum of 1000N. The reaction forces at the pivot and the head tube are recorded. The maximum force that can be exerted on the U-bracket without considering the damping action of the spring is found to be 1520N. This is when the force exerting on the pivot of the main frame is transmitted completely to the rear triangular frame. where it is transmitted to the spring first, then the quick release bolt and then to the U-bracket attached to the frame. usually, the estimated load is more than the conditional load applied for the trike. The results can be different for the type of material used.

IV. RESULT

A. Folding Motion Analysis

The pivotal axis is positioned at the intersection of main frame and the rear triangular suspension frame. Axis of rotation should be fixed according to the position of the axis from the ground in terms of height and length that determines the z-axis height after folding. The main frame being fixed about its geometry and the front steering v-plate ending the path, the parallel orientation is not possible after the folding. The azimuthal angle (φ_L) is found to be 129.8° and the polar angle is 0° as offset is not required for the trike for the parallel alignment. However, the three wheels can not align for the pre-decided trike geometry.

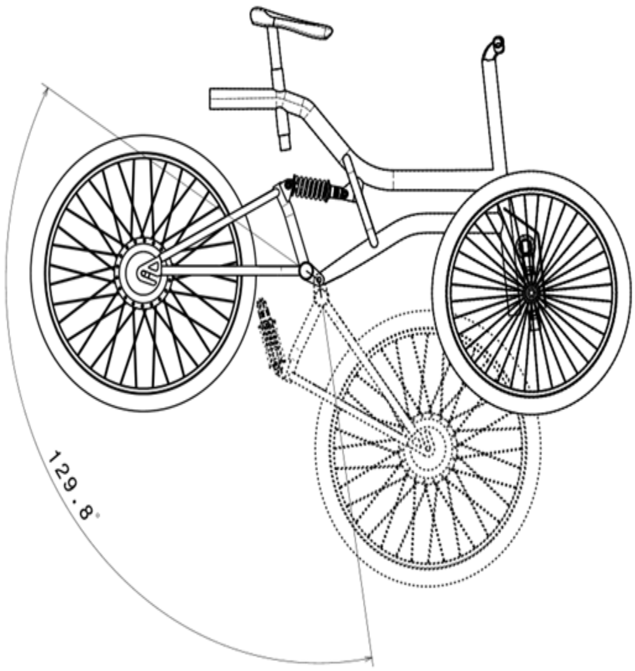

Fig 5:- Folding Angle at its Maximum

The range of the angle can be increased only if the chain stay rod length is ¾ of the actual length to completely touch the base rod. Another possibility is that the wheel size can be reduced to skip the contact of the v-plate of the steering. But, doing so reduces the efficiency of the drive for the selected specification of the motor.

B. Space Optimization

The rear wheel is 24in and the front wheels are 20in. The height of the front end could be increased using 24in wheels. This would allow another 10-15 degrees of azimuthal angle (φ_L). As already the use of 24in wheels make the trike heavy, they cannot be afforded to be placed at the front. Initial unfolded dimensions are shown below (Fig. 6).

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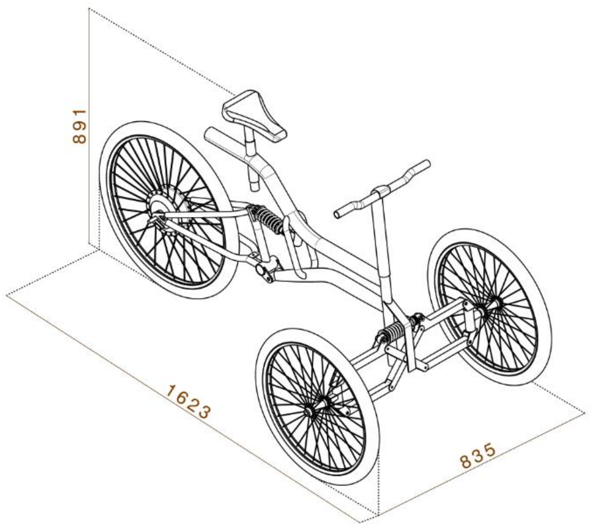

Fig 6:- Initial Dimensions of the Trike

The dimensions of fold remain constant in terms of width. The reduction of length is observed to be 612 mm. But height is increased to 1223mm from 891mm due to the alignment of the wheels' base to the ground to keep it steady without any support (Table. 2).

Folding mechanism type	Size (Length x height x width; mm)	Folded size (Length x height x width; mm)
SLP	1623 x 891 x 835	1011 x 1223 x 835

Table 2:- 1-D Geometry Reduction

The reduced length of the folded trike is almost equal to the wheel base of the trike i.e., 1045mm (Fig. 7).

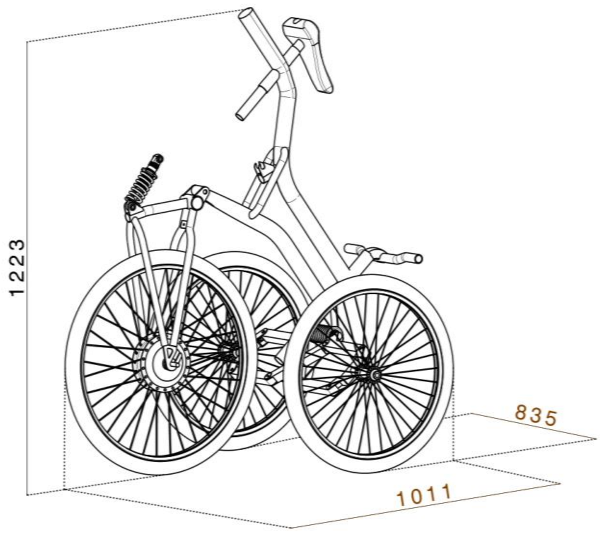

Fig 7:- Fold Dimensions of the Trike

In terms of area and volume, though there is a decrease in the area corresponding to the height of fold, the base should atleast be prominently satisfactory. Supportively (Table. 3), it can be observed that the reduction in base is 37.7%. while the decrease in height x length area is 14.5%. This is same as the volume reduction % observed as the track width is constant throughout.

The use of quick release clamps at the seat post and the handle bar reduced the volume boundary. The handle bar has two features. One with a height adjustment and other lower part with a foldable joint whose strength is of most importance especially while braking and steep riding.

	Unfolded	Folded	% reduction
Base area, m^2	1.355	0.844	37.7
Overall volume, m^3	1.207	1.032	14.5

Table 3:- Base area and volume transformation

C. Foldable Joint Strength

As stated before, the foldable joint and axis are different. The load bearing capacity at the pivot is as usual as it would bear the load under common cycling conditions. Whereas, the pivot is removable and is cut. So, the strength at the joint is evaluated using ANSYS software for simulation and found to a maximum of 375.22 MPa (Fig. 8).

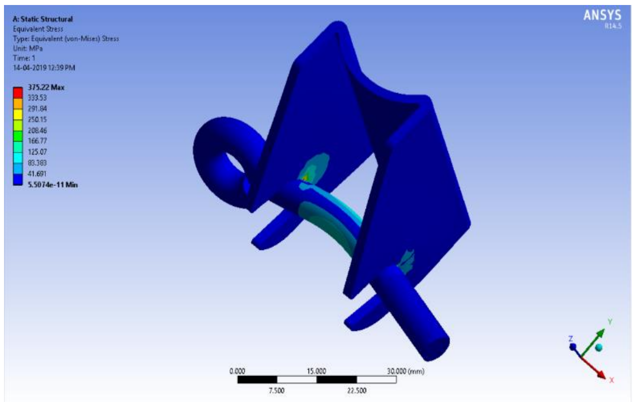

Fig 8:- Equivalent stress result of the joint

Maximum stress is concentrated in a very small region of intersection of two bodies. On an average at other parts, the stress induced is less or negligible about a range of 5.5×10^{-11} MPa to 125 MPa. As the loads applied are maximum without damping considered and also the obtained range of acceptable stress throughout the joint is less than the materials' yield stress i.e., 207 MPa, the joint will be safe.

The deformation is negligible as the maximum magnitude of deformation is about 0.03448mm. Maximum deformation region is at the loop of the bolt. At center of the bolt, deformation is about 0.030649mm (Fig. 9). The U-bracket is not affected by the load while the bolt is subjected to the primary deformation. Hence, the quick release can be easily replaced if failed under fatigue loading in long run.

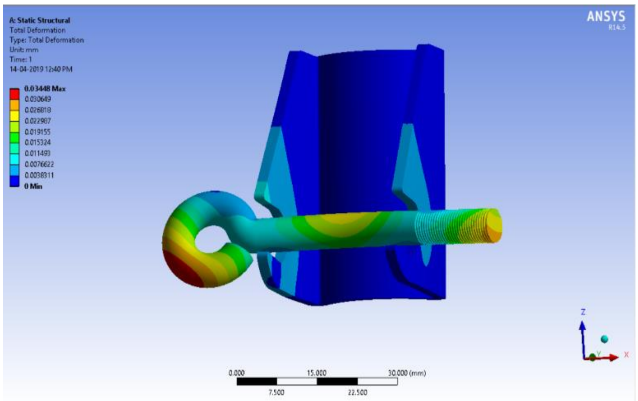

Fig 9:- Equivalent stress result of the joint.

V. CONCLUSION

Not only the bicycle, the trikes can also be made portable common usage purpose acknowledging the design parameters used for the bicycles as reference. For the fixed geometry of the trike considered, Single Lateral Pivot (SVP) is possible with some modification to the existing design. For this, a foldable joint is chosen to be the spring and U-bracket intersection supported by a quick release clamp. Subjects like range of fold, space occupancy and strength of the joint after evaluated, the following conclusions can be made.

- Dissimilar locations of folding joint and pivot can produce similar results of fold with some alterations in design.
- The maximum azimuthal angle (φ_L) is $129.8^o \approx 130^o$ and polar angle is 0^o as not necessary for the selected geometry.
- The track width is constant throughout and base length is decreased by 612mm. But the height is increased by 332mm after the fold as the base plane is shifted according to the orientation of wheels.
- The reduction in base area is 37.7% and that of volume is 14.5%.
- The path-oriented tangential cut U-bracket is found to have no effect due to the load as the maximum deformation is 0.011493mm. Also, the quick release bolt with a deformation of 0.03448mm can also be neglected.
- von-Mises stress for clamp bolt is maximum of 125 MPa, less than its yield strength. So, the clamp is safe and can be replaced easily under fatigue failure in the future.
- Stress concentration is most at the intersection of U-bracket and loop region of the bolt.

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