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Research Article

Steering of an Automobile using Belt Drive

A. Padma Rao [Ȧ*] and R. Venkatachalam [Ḃ]

[Ȧ] Mechanical Engineering Department, Kshatriya College of Engineering, Chepoor, Armoor – 503224, Andhra Pradesh, India.
[Ḃ] Mechanical Engineering Department, National Institute of Technology, Warangal 506 004 India

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Abstract

Steering plays a vital role in the proper functioning of any road vehicle. Even in the present era of electronics, the electronics could not enter the steering system because of various practical difficulties. Mechanical linkage provides foolproof, reliable and positive drive for the steering. Ackerman mechanism which is essentially a four bar linkage is popularly used in the automobile industry. Though this mechanism cannot provide perfect steering, it is widely used because of its simple constructional features. In this paper an attempt is made to develop a mechanism which may replace the Ackerman mechanism. The proposed mechanism is also purely mechanical, simple, reliable and gives steering better than Ackerman mechanism.

Key words: *Steering, Ackerman mechanism, belt drive*

1. Introduction

One of the important systems of an automobile is the steering system. In a two wheeler, the rider turns the front wheel handle bar. The vehicle starts moving in a circular path whose centre is located at O the point of intersection of the axes of the rear and front wheels as shown in Figure 1. It is to be observed that the planes of rotation of the wheels are tangential to the circular path.

In a four wheeler, right side front and rear wheels may be imagined to form one two wheeler and left side front and rear wheels to form another two wheeler. It is a common practice to provide steering only to the front wheels. If the front wheels are turned arbitrarily as shown in Figure 2, then the right side front and rear wheels try to follow a circular path whose centre is at O_2. Similarly, the left side front and rear wheels follow a circular path whose centre is at O_1. Clearly, these two circular paths are not concentric and the motion of the wheels is not going to be smooth. That is, the front wheels start skidding on the road. It is therefore observed that if the vehicle has to take a turn smoothly the two circular paths must be concentric which demands a condition that O_1 and O_2 should be the same point as shown in Figure 3. The whole vehicle follows a circular path whose centre is at O. The two front wheels will make rolling on the road without skidding. This is treated as perfect steering. The condition for perfect steering may now be stated as when the axes of the two front wheels are extended, they should intersect at a point on the extension of the common axis of the rear wheels. In Figure 3 the vehicle is shown taking a right turn.

The stub axles on which the front wheels are free to rotate, are hinged to chassis at points A and B. The distance between A and B is called track width, W. The distance between AB and common rear wheel axle EF is called wheel base, H.

In Figure 3 the inner wheel is shown to rotate by an angle ø and the outer wheel is shown to rotate by an angle θ. It is observed that ø > θ. From the geometric consideration of the perfect steering condition shown in Figure 3, a relation connecting ø and θ may be derived as

$$\cot\theta - \cot\phi = W/H \qquad (1)$$

Equation (1) describes the condition for perfect steering. It is to be observed that the angles θ and ø are related to the physical dimensions W and H of the vehicle. For a given value of W/H, one can numerically solve the Equation (1) for ø for different values of θ. These values of θ and ø are listed in first two columns of the Table 1.

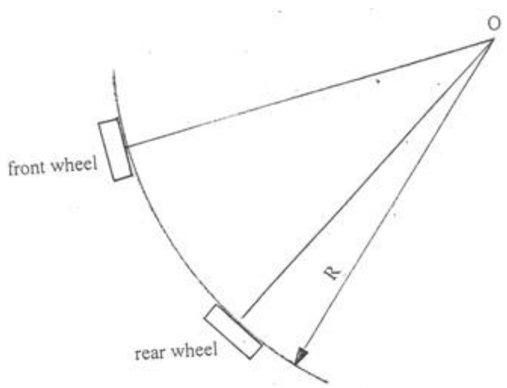

Figure 1 A bicycle taking a right turn.

*Corresponding author: **A. Padma Rao**

Table 1 Performance study of the proposed mechanism.

ø (deg)	**θ (deg)**	**θ* (deg)**	**Δθ (deg)**	**e**	**ε (mm)**
0	0	0	0	---	---
1.01	1	0.743	0.256	25.614	-46964.7
2.04	2	1.502	0.497	24.860	-22565.2
3.09	3	2.277	0.722	24.090	-14434.8
4.16	4	3.067	0.932	23.306	10371.8
5.26	5	3.874	1.125	22.507	-7935.8
6.38	6	4.698	1.301	21.694	-6313.6
7.52	7	5.539	1.460	20.868	-5156.4
8.68	8	6.397	1.602	20.027	-4289.9
9.87	9	7.274	1.725	19.174	-3617.4
11.09	10	8.169	1.830	18.308	-3080.6
12.33	11	9.082	1.917	17.431	-2642.7
13.59	12	10.014	1.985	16.542	-2279.0
14.89	13	10.966	2.0335	15.642	-1972.5
16.1	14	11.93	2.06	14.733	-1710.9
17.55	15	12.927	2.072	13.816	-1485.3
18.92	16	13.937	2.062	12.890	-1289.1
20.32	17	14.967	2.032	11.958	-1117.1
21.74	18	16.016	1.983	11.021	-965.3
23.19	19	17.084	1.915	10.081	-830.6
24.67	20	18.172	1.827	9.138	-710.5
26.17	21	19.279	1.720	8.194	-603.0
27.70	22	20.404	1.595	7.252	-506.3
29.26	23	21.547	1.452	6.313	-419.2
30.83	24	22.709	1.290	5.379	-340.4
32.43	25	23.886	1.113	4.452	-269.1
34.05	26	25.081	0.918	3.534	-204.3
35.70	27	26.290	0.709	2.627	-145.5
37.36	28	27.514	0.485	1.735	-92.0
39.04	29	28.751	0.248	0.858	-43.3
40.73	30	30.000	-2.9E-05	-9.8E-05	01.0

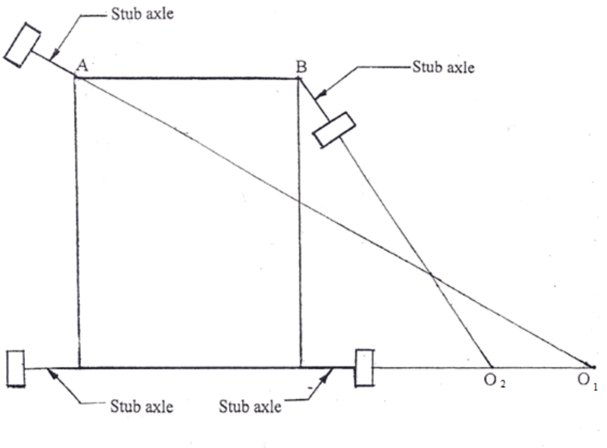

Figure 2 Steering offered by Ackerman mechanism

In actual road vehicles, the inner wheel stub axle normally does not turn more that 30˚. That is why the values are computed for $0 \leq \theta \leq 30^\circ$.

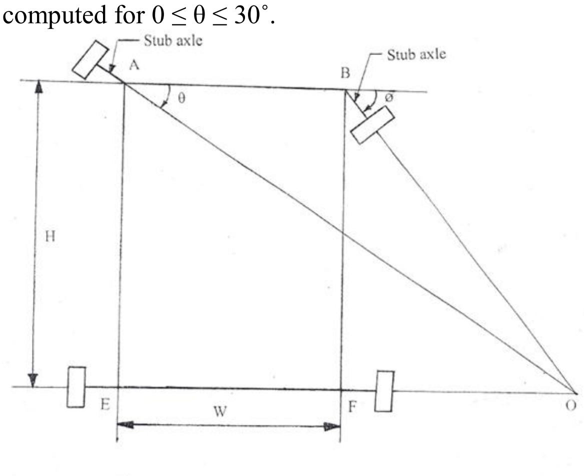

Figure 3 A car taking a right turn.

2. Steering Mechanism

An ideal steering mechanism must be such that it should provide angles of turn θ and ø of the front wheels according to the perfect steering condition expressed in Equation (1).

One mechanism which is popularly being used is the Ackerman mechanism shown in Figure 4. The mechanism consists of two bell crank levers GAC and JBD which are hinged to chassis at points A and B, respectively. The actual mechanism ABDC is a four bar mechanism. When the mechanism is operated, it may occupy a position such as ABD'C' as shown in Figure 5. The Ackerman mechanism ABDC shown in Figure 4 represents the vehicle while moving along a straight path. Since the same mechanism produces similar turns of the stub axles for both right and left turns of the vehicles, the mechanism is expected to be symmetric about vehicle centre line. This feature may be observed in Figure 4, as being in the form of an isosceles trapezium. In Figure 5 the steering offered by Ackerman mechanism is shown. Clearly, it is not a perfect steering. The Ackerman mechanism may give perfect steering in three positions namely, while moving along a straight path and one particular position in the left turn and one particular position in the right turn. Though this mechanism cannot give perfect steering always, it is widely accepted in the automobile industry because of its simple constructional features.

Deep studies on the Ackerman mechanism must have been performed by the automotive industries. But they are not available in the published literature, may be because of confidentiality. Some of the recent papers suggesting modifications on Ackerman mechanism are studied (Okamoto, *et al* 1977, Nakahama, *et al* 1985, Kamner, *et al* 1967, Hornagold, *et al* 1978, Tapp, *et al* 1979, Kamble, *et al* 2005). The authors (Venkatachalam, *et al*, 2010) presented the method of analysis of the Ackerman mechanism for studying its performance. The method proposed by the authors helps to estimate the skidding of the tires due to incorrect steering.

The authors (Venkatachalam, *et al*, 2011) also attempted to optimize some of the dimensions of the Ackerman mechanism in order to make the steering offered as close as possible to perfect steering. Simple optimization principles are applied and the results are found to be very encouraging. However, the mechanism is still unable to provide perfect steering throughout.

As an alternative, one may think of having a dedicated microprocessor which senses the angle of the turn of one front wheel, calculate the required angle of turn of another front wheel, and send a signal to a motor which rotates the other front wheel by the required angle by applying sufficient of torque. However, there are practical difficulties such as response being slow and the drive not being positive. That is, the motor may apply the torque to turn the front wheel but the wheel may not turn because of any obstructions offered by the stones or loose soil present between the road and tires. Further, the electronic components may not offer reliable service. A mechanical means would be reliable and can provide a positive drive.

In this paper an attempt is made to replace the Ackerman mechanism with a simple arrangement which can also provide a positive steering drive.

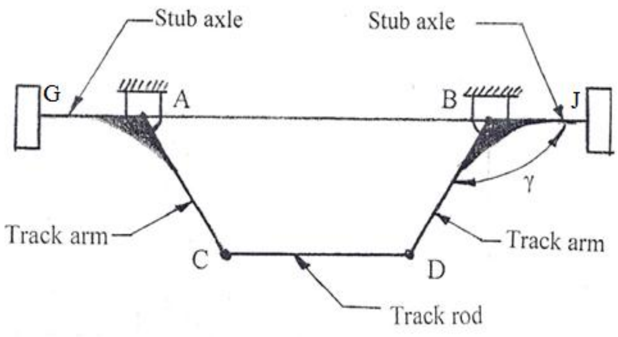

Figure 4 Ackerman steering mechanism

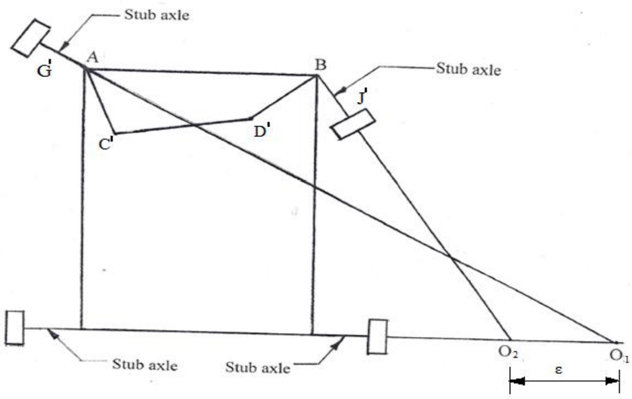

Figure 5 Steering offered by Ackerman mechanism

3. Synthesis of Mechanism

Figure 6 shows the description of the proposed mechanism. It essentially consists of two discs (pulleys or sprockets) which can rotate about points A and B. The stub axles of the front wheels are integral parts of these discs. The rotations of these two discs are coupled using a belt drive. Let r_A and r_B be the radii of the two discs.

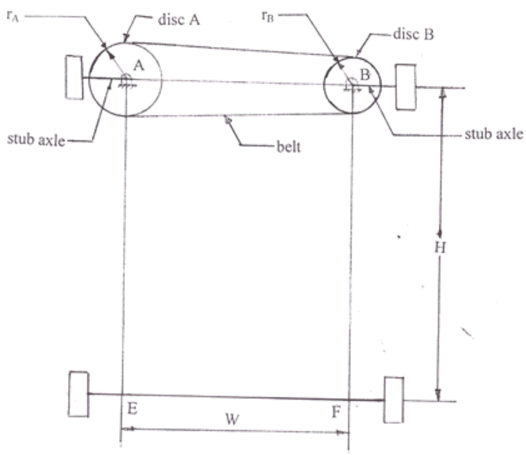

Figure 6 Proposed mechanism.

From the values listed in Table 1, it is observed that for a total rotation of 30˚ of the outer stub axle, the inner stub axle undergoes a total rotation of 40.738˚. This can be accomplished using a belt drive shown in the proposed mechanism. The radii of the two discs may now related as

$$r_B / r_A = 30/40.738 = 0.7364 \quad (2)$$

For a given value of r_B, the required value of r_A can be calculated. This ensures that when the inner stub axle rotates through 40.738˚, the outer stub axle rotates through 30˚. It is not guaranteed that the correct steering is satisfied throughout. Therefore, it is a matter of interest to see how well this arrangement may provide the steering.

4. Analysis of the Proposed Mechanism

In order to see the performance of the proposed mechanism, first the radius r_B is taken as 5 cm. The corresponding value of r_A may be obtained as 6.7896 cm. The inner stub axle angle ø is varied in steps of 1˚ and the corresponding values of the angles θ* through which the outer stub axle is turned by the proposed mechanism, are obtained. These values are tabulated in the third column of Table 1. The table also shows the difference Δθ between the desired value of θ for correct steering and the value θ* given by the present mechanism. The percentage error e and the steering error ε are also calculated and tabulated in Table 1.

Figure 7 shows the variation of values of θ, θ*, Δθ, e, ε with ø. One may attempt to do a similar analysis with a different value for radius r_B. But the results would be identically the same as what is presented for r_B = 5 cm because though the radii of the pulleys are different, they are maintaining the same ratio. Hence, if one wants to adopt this mechanism, any r_B may be chosen based on practical space limitations such as the space availability.

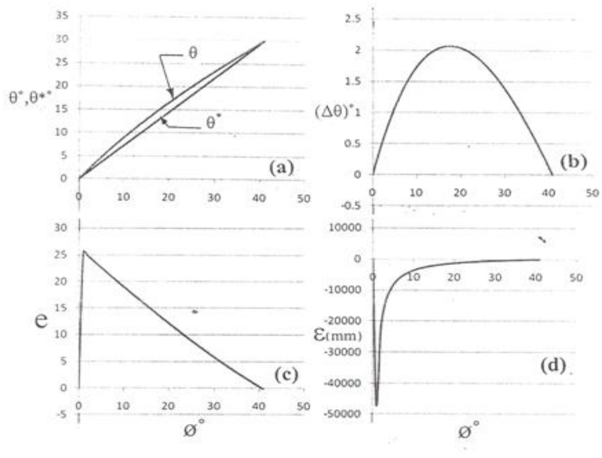

Figure 7 Analysis of the proposed arrangement

5. Discussions

In Figure 7a the variation of θ and θ* are shown. The variation of θ* with ø is a linear variation which is because of the pulley drive adopted. The mechanism proposed is giving a value θ* which is always less than the desired value θ. However, θ and θ* are same at end points. This is consequence of the way r_B is fixed as in Equation (2). The proposed mechanism certainly does not give correct steering except at the end points.

Figure 7b shows the variation of Δθ. A maximum value of Δθ is noticed when ø is 17.5˚. The maximum difference is around 2˚. This much of inaccuracy may be tolerable, as a reasonably accurate steering could be achieved through this arrangement. It is worth mentioning here that the analysis on Ackerman mechanism done by the authors showed a maximum deviation of 5˚. Therefore, the proposed belt arrangement is seen to give an error less than Ackerman mechanism.

Figure 7c shows the variation of percentage error in θ. Maximum percentage error of 25% is occurring in the beginning and is gradually reducing towards the end.

Figure 7d shows the steering error ε. The steering error is maximum in the beginning and is decreasing very rapidly to zero in 10˚ turn of the front wheel. Though ε value appears to be very large in the beginning, one should not have a feeling that the steering is highly erroneous. The value of ε should be compared with the radius of curvature of the path. In the present case the radius of curvature R is very large (tending to infinity) in the beginning. Hence, ε/R is very small. Therefore, one may conclude that in the beginning also reasonably accurate steering is achieved. If ε itself is zero then one can say that the steering is accurate. This is happening for 10˚<ø<40˚.

The belt arrangement is maintaining a constant ratio of the rotations of the two pulleys. Such a thing may also be obtained using gear wheels as shown in Figure 8. G_A and G_B are the two gear wheels to which the stub axles are attached. The diameters (or number of teeth) on these gears may be determined as in Equation (2). G_A and G_B are connected through required number of idle gears such that the two gears G_A and G_B have the same sense of rotation (clockwise or counter clockwise). For this, the number of idle gears is to be odd in number. This arrangement should also give the same performance as in the case of belt arrangement.

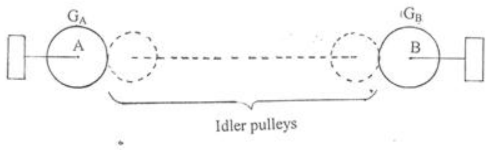

Figure 8 Replacing the proposed mechanism by a simple gear train arrangement

6. Conclusions

The significant conclusions that may be drawn on the basis of the present work may be summarized as follows.

i. A belt drive arrangement is proposed for providing steering for four wheeler.
ii. The proposed arrangement is not without any error. But the errors are less than the conventional Ackerman mechanism.
iii. The proposed mechanism may replace the Ackerman mechanism.
iv. The steering offered by the proposed mechanism is positive and reliable.
v. In order to avoid the slippage which is

inherent drawback of belt drive, one may use chain drive with sprockets.

vi. By use of simple gear train also, one may achieve same steering.

References

Okamoto, A.A. and Chikuma, I. (Steering gear division, Nippon Seiko), The design concept of an integral power steering system for heavy duty trucks, SAE Transactions, 1977. (Report no.770673)

Nakahama, M., Momiyama, F. and Ueda, T. (Hino Motors Ltd.), Load and / or speed sensing power steering for medium and heavy trucks, SAE Transactions, 1985. (Report no.770673)

Kamner, H.J., Combined articulated and Ackerman steering system for vehicles, United States Patent No. 3 515 235, 1967.

Hornagold, J.T., Beckley, G.H. and Rathi, R.N., Steering mechanism, United States Patent No. 4 109 747, 1978

Tapp, G.E.E., Steering mechanism, United States Patent No. 4 163 566, 1979.

Kamble, N., Saha, S.K., Evaluation of torque characteristics of rack and pinion steering gear using ADAMS model 2005-01-1064, SAE 2005-Transactions,

Journal of passengers Cars-Mechanical systems, June 2005, pp. 1217-1222.

Kamble, N. and Saha, S.K., Developing a virtual prototype of a rack and pinion steering system, International Journal of Vehicle Systems Modelling and Testing, Vol 2006.

Venkatachalam, R. and PadmaRao, A., Estimation of skidding offered by Ackerman mechanism, Journal of The Institution of Engineers (India), Vol. 92, 2011, (In Press).

Venkatachalam, R. and PadmaRao, A., Graphical approach for optimum design of steering mechanism, Proceeding of 4th International Conference on Advances in Mechanical Engineering, S.V. National Institute of Technology, Surat, Gujarath, September 23-25, 2010, pp. 100-104.