Steering System Optimization for Vehicle Drift

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Abstract— Steering system is used to steer the front wheels in response to driver inputs in order to provide overall directional control of the vehicle. Thus, Steering system plays very important role in vehicle handling characteristics. Vehicle drift i.e. deviation of vehicle path from straight line during braking is related various parameters of Suspension, Steering, Tires, Wheel alignment etc. Analysis of steering characteristics such as Brake and bump steer which affects vehicle drift plays an important role.

Modeling and analysis of vehicle have been performed in a multi body dynamics environment based on actual vehicle data for Bump and Brake Steer. The same is verified by subjective assessment. Different steering linkage concepts have been proposed to vehicle drift. Further optimization of hard points is done to reduce vehicle drift within packaging constraints. It is found out that drag link ball joint position plays an important role in brake and bump steer.

Index Terms—ADAMS, Steering, Vehicle Drift

I. INTRODUCTION

Vehicle drift is a condition where a vehicle deviates to one side of the road during braking. This is not a violent condition but is an unfavorable handling characteristic. Vehicle Drift or pull creates driver discomfort, where a driver has to apply constant correcting steering wheel torque in order to maintain the desired path [1].

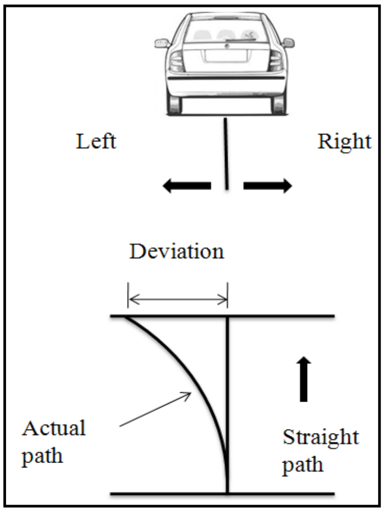

Fig.1: Vehicle Drift

When a vehicle travel across bump, spring deflects and the front axle and all attached parts move up and down. The path of motion of the axle and attached parts can be defined by treating the spring as a three link mechanism as described in SAE J788a Manual on Design and Application of Leaf Springs. The arc of travel of the steering arm ball and the center for this arc is as shown in Figure 2.

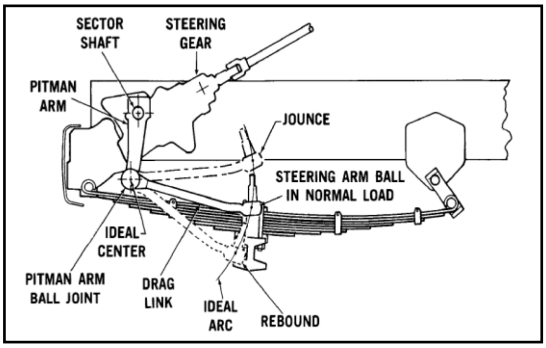

Fig. 2: Ideal location of Pitman arm ball joint [2]

If the pitman arm end of the drag link is not on the center of the arc of the steering arm ball travel then Bump steer occurs [2].Pitman arm drag link hard point, Deflection curve of springs affects the bump steer.

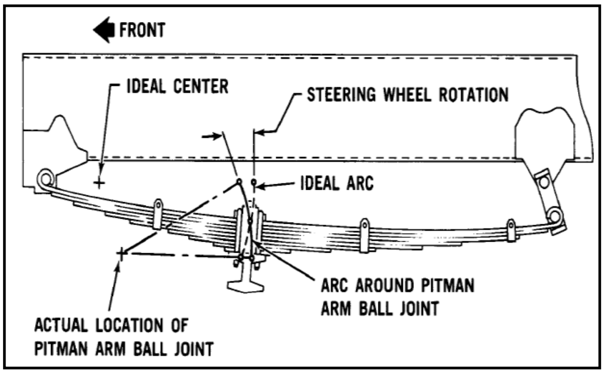

Fig 3: Bump Steer Phenomena [2]

The location of the steering arm ball joint affects vehicle directional stability in severe brake applications. Spring rotates as braking torque is applied, thus any point on the un sprung components other than the centre of rotation is displaced. Spring stiffness, Steering arm drag link ball joint affects the Brake steer [2].

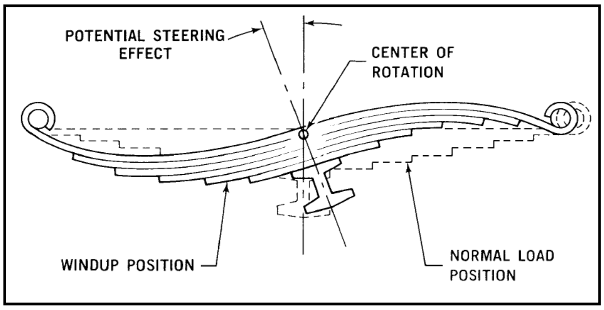

Fig. 4: Spring wind up - Brake Steer Phenomena [2]

Multi body dynamics software (MBDS) such as ADAMS can be used to simulate the vehicle, which saves time, cost to great extent. The vehicle under study is modeled in ADAMS and simulated for Bump & Brake steer. The steering system is then optimized to reduce same [1].

II. MODELING AND ANALYSIS OF VEHICLE IN ADAMS

The Vehicle front end which consists of aggregates such as steering, suspension, tires, axles is modeled in ADAMS.

A. The brief Vehicle specifications

Parameter	Details
GVW, Kg	4500
Front Axle Weight, Kg	2150
Front Track	1700
Wheel Base	2800
Steering	Recirculation ball type Inner: 36º , Outer:25º
Suspension	Leaf Spring
Tire	All Terrain Tire
SLR	420
Axle	Rigid axle
Brakes	Drum Brakes at front and rear

Table I: Brief Vehicle Specifications

B. Hard points of Steering and suspension system

Hard points are Ball joint points where linkages such as drag link, tie rod are connected. Different had points of vehicle under analysis are as shown in Figure 5.

Ball joints are spherical joints which allow movement in all three directions. If rigid joint used, it will cause failure.

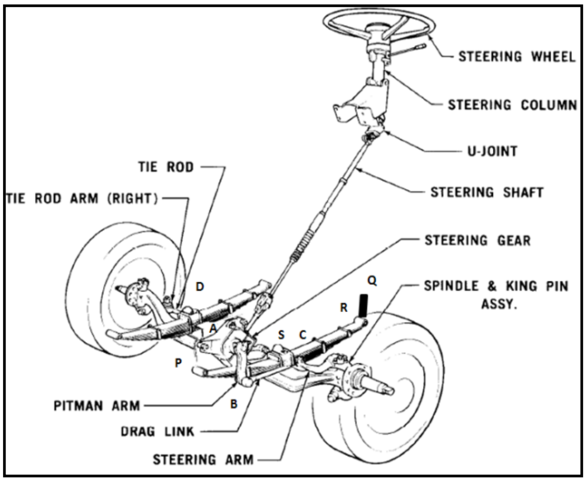

Fig. 5: Typical Steering system and hard points [2]

Hard point	Description
A	Pitman Arm Gear Box
B	Pitman Arm Drag Link Ball Joint
C	Drag link Steering arm Ball Joint
D	Tie Rod arm Tie rod Ball Joint

Table II: Steering Hard points

C. Brake Torque calculations

Height of CG from ground, mm =900
Deceleration value, g =0.7
Static loaded radius, mm =420
Weight transfer to front axle

$$= \frac{\text{Decelleration} * \text{Height of CG} * \text{GVW}}{\text{Wheelbase}}$$

$$= \frac{0.7 \; * 900 * 4500}{2900}$$

$$= 977.5 \text{ Kg}$$

Weight transfer to each tyr

$$= \frac{\text{Weight transfer to front axle}}{2}$$

$$= 488.8 \text{ Kg}$$

Now,

Total Weight on each front tyre

$$= \text{Weight transfer to each tyre} + \frac{\text{FAW}}{2} = 488.8 + \frac{2150}{2}$$

$$= 1563.8 \text{ Kg}$$

Brake Torque per wheel

$$= \frac{\text{Decelleration} * \text{Total Weight on each front tyre} * \text{SLR}}{1000}$$

$$= \frac{0.7 * 1563.8 * 420}{1000}$$

$$= 459.7 \text{ Kg} - \text{m}$$

D. Modeling in ADAMS

Multi body dynamics software (MBDS) such as ADAMS has the capability of performing simple or complex simulations and can be used for large displacement, static, kinematic and dynamic analyses of interconnected bodies.

Vehicle front end template has been created in ADAMS as shown in below figure. The template is modified as per vehicle under analysis by input of suspension hard points, steering and brake related information.

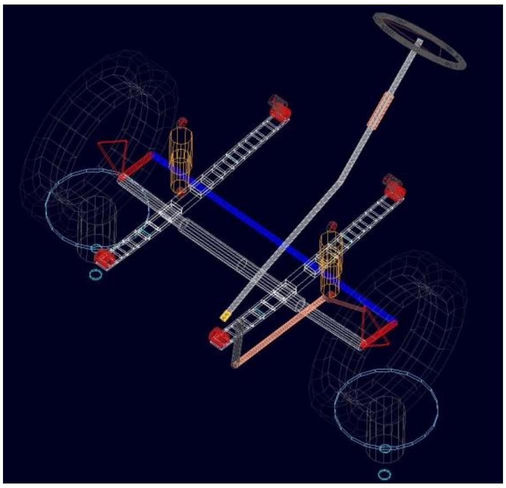

Fig. 6: ADAMS model for Bump and Brake steer calculations

The leaf spring is modeled as series of links connected by bushes having tensional stiffness such that whole leaf spring has desired vertical rate. Tensional preloads in bushes are required in addition to stiffness to achieve equilibrium in absence of any vertical force.

A Hotchkiss front suspension with pitman arm, drag link steering is modeled in ADAMS using hard points at flat spring condition and the leaf spring model. All necessary forces and constraints are incorporated to carry analysis.

Correlation of ADAMS analysis and experimental results has been achieved [5]-[6].

E. Simulation of vehicle in ADAMS

The vehicle is then simulated to find brake and bump steer. Typical bump and brake steer graph is as shown in below figure.

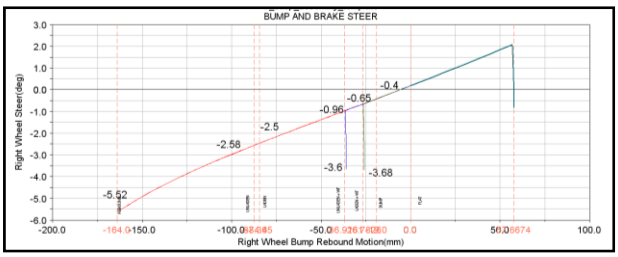

Fig. 7: Brake and Bump steer graph

From figure 3.3,

$$\text{Bump Steer in Laden} = \frac{\text{Wheel steer angle in laden} - \text{Wheel steer angle in bump}}{\text{Wheel travel from laden to bump}}$$

$$\text{Bump Steer in Laden} = \frac{-2.5-(-0.4)}{65.48}$$

Bump Steer in Laden= $1.92\ \text{min/mm}$

From Vertical line ordinates,

$$\text{Brake Steer in Laden} = -3.68-(-0.65) = -3.03\ \text{deg}$$

Thus, it is found out that brake steer value is -3.03 deg. Negative sign indicates left side which is too high and not acceptable. Hence new steering linkage concept needs to be prepared within available packaging constraints

III. DEVELOPMENT OF CONCEPT TO REDUCE BUMP AND BRAKE STEER

There are many parameters that affect brake and bump and brake steer. Only steering parameters i.e. hard points which affects are considered. The Steering arm, pitman arm hard point has been varied within vehicle packaging constraints.

A. Packaging constraints

As Axle is under slung, it is not possible to take steering arm BJ down towards center of leaf spring.

All adjacent parts of steering linkages are carryover and developed. Major modification of same will lead to large development cost as well as time which were not accepted.

Considering these constraints different concepts has been proposed to reduce brake and bump steer and evaluated using Pugh concept selection technique as below

B. Different concepts of steering linkages proposed

Concept 1: Datum concept

Concept 2: Stg Arm BJ down by 20mm, Pitman arm BJ to front by 20 mm

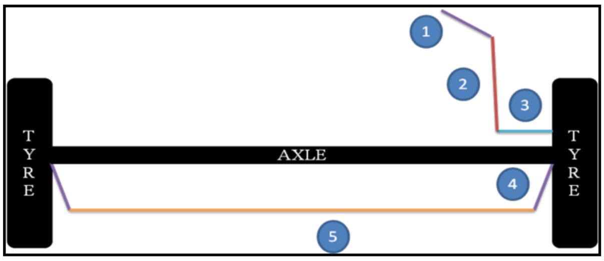

Fig. 8: Concept 1, 2 Steering Linkages
Concept 3: Drag link on tie rod at front

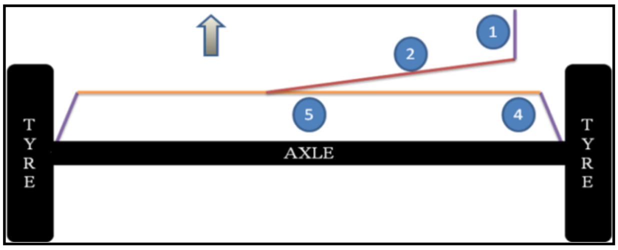

Fig. 9: Concept 3 Steering Linkages

Concept 4: Drag link on left stub axle, Tie rod behind axle

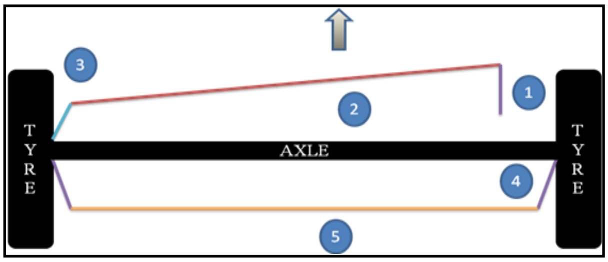

Fig. 10: Concept 4 Steering Linkages

Where,
1: Pitman arm
2: Drag Link
3: Steering Arm
4: Tie Rod Arm
5: Tie Rod & arrow indicates vehicle front.

These different concepts are evaluated using Pugh concept selection matrix as shown in Table III.

”S” indicates it is same as in Datum concept.

“+” indicates it is better than Datum concept.

“-“indicates it is below the Datum concept.

The Concept 4 i.e. Drag link on left stub axle, Tie rod behind axle is having more overall score hence it is selected for further optimization.

	Parameter	Concept 1	Concept 2	Concept 3	Concept 4
Criteria	Bump Steer	Baseline	S	+	+
	Brake Steer		+	+	+
	Net Effect		+	+	+
	Packaging feasibility		-	+	+
	Carryover components		S	-	S
	Development time		S	-	S
	∑ +		2	4	4
	∑ -		1	2	0
	∑ S		3	0	2
	Overall Score		1	2	4

Table III: Pugh concept selection matrix

IV. OPTIMISATION OF CONCEPT

Concept 4 hardpoints are optmised to reduce bump and brakesteer. The hardpoi nts varied are Drag link pitman arm hardpoint, Drag link stub axle hardpoint.The Final optimised layout is shown in below figure

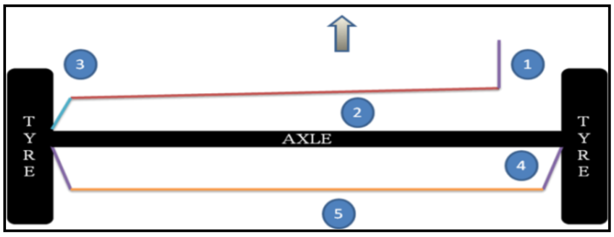

Fig. 11: Optimized Steering Linkages

Different iteration are performed on concept 4 to optimize are shown in table 4

Parameter	Brake Steer	Bump Steer	Bump Steer (During Braking Event)	Net Effect
Unit	Deg	min / mm	Deg	Deg
Base	0.94	0.08	0.14	1.02
Iteration 1	0.44	0.48	0.79	0.92
Iteration 2	0.26	0.43	0.72	0.70

Table IV: Concept 4 optimization

In above iterations hard points are varied as shown in table IV.

		Iteration 1	Iteration 2
Pitman Gear Box	Base	Taken to rear by 260 mm	Taken to front by 51 mm , outside (Y) by 22mm
Drag link Pitman arm Ball Joint		Pitman Length increased to 241 mm	No change
Drag Link Steering Arm Ball Joint		No Change	Taken up by 25mm

Table IV: Concept 4 optimization Iteration

V. RESULT AND DISCUSSION

The Current vehicle has been modeled in ADAMS for Bump and Brake steer calculation. The net effect of bump and brake steer indicates the vehicle drifting to left side. The subjective assessment of same vehicle is done which also indicates left side pulling. Thus values obtained by ADAMS are in good agreement with subjective assessment of vehicle.

As these values were high, which is safety concern, different concepts of steering linkages are prepared. Using Pugh concept selection matrix the best concept considering packaging constraints, maximum carryover parts, brake, bump steer values and development time is selected. The selected steering system linkage concept has been optimized by varying different drag link ball joints.

The comparison of existing and optimized steering system design is shown in table V.

Parameter	Brake Steer	Bump steer	Bump steer (During braking event)	Net Effect
Unit	Deg	min/mm	Deg	Deg
Existing	-3.03	0.95	0.57	-2.46
Optimized	0.30	0.70	0.42	0.72

Table V: Results Comparison

It can be seen from above table that Bump steer is improved by 26% while Brake steer is improved by 90%. The net effect indicates marginal pulling of vehicle to right side which is acceptable.

VI. CONCLUSION

In present paper current vehicle steering system has been analyzed for bump & brake. The different hard points which affects bump and brake steer have been studied. It is found that steering arm and pitman drag link ball joint affects these parameters.

The vehicle has been simulated using MBD software ADAMS. To reduce brake and bump steer, different steering linkage concepts were worked out considering constraints. Among this, drag on left stub axle linkage is optimized for brake and bump steer.

It is found out that drag link ball joint position plays an important role in brake and bump steer.

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