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Comparision of Steering Geometry Parameters of Front Suspension of Automobile

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Abstract— Paper details the comparison of steering geometry parameters such as kingpin inclination angle, caster angle, camber angle, toe angle calculated from experimental observations, experimental data based model and artificial neural network theory. New techniques present the prediction of vehicle performance from the point of view of steering performance and comparison of steering performance of other vehicles.

Index Terms—Artificial Neural Network, Automobile, Comparison, Experimental, Suspension, Steering, Vehicle.

1 Introduction

THE Vehicle presents major challenges in terms of servicing and maintenance. Worn suspension bushings causes inconsistency in steering parameters. Steering geometry is very sensitive to even slightest distortions in bushes of suspension joints.

Steering performance parameters kingpin angle, caster angle, camber angle, toe angle, scrub radius, toe in and toe out of front suspension of vehicle are determined based on experimental observations, data based model and artificial neural network is compared. New techniques present the prediction of vehicle performance from the point of view of steering performance and comparison of steering performance of other vehicles.

Presently paper details the comparison of steering geometry parameters such as kingpin inclination angle, caster angle, camber angle, toe angle calculated from experimental observations, experimental data based model and artificial neural network theory.

2 Front Suspension

2.1 Steering Geometry

The six included angles of the 3D front suspension mechanism, one at each revolute joints and two at each spherical joints of this four bar chain, position of kingpin axis is determined. Steering performance depends on the position of kingpin axis. Depending on the position of Kingpin axis, Caster angle, Camber angle, Kingpin angle and toe angle of four wheel vehicle are decided.

Joint O_1 and O_2 are revolute joints and joints A and B are Spherical joints as shown in Figure 1. The relative orientation of two links connected at joint can be decided in terms of magnitudes of included angles which in turn can be measured by potentiometer and associated electronic instrumentation. Six potentiometers are located at four joints (two spherical and two revolute) of the RSSR mechanism. At revolute joints O_1 & O_2 the one included angle each of these joints and at spherical joints A & B the two included angles at each of these joints.

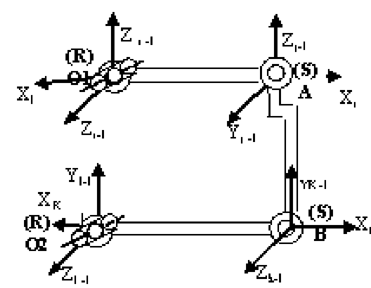

Fig. 1. : RSSR - Revolute Spherical Spherical Revolute

2.2 Steering Parameters

• Kingpin axis: The steer angle is achieved by rotation of the wheel about a steer rotation axis. This axis is kingpin axis is shown in figure.

• Kingpin inclination angle: Angle in front elevation between the steering axis and the vertical.

• Caster angle: angle in side elevation between the steering axis and the vertical.

• Camber angle: Inclination of the wheel plane to the vertical

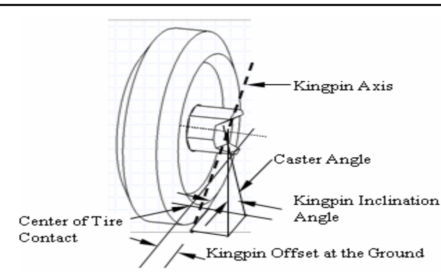

Fig. 2. : Front Suspension of an Automobile

3. Formulation of an Experimental Data Based Model

3.1 Identification of Physical Quantities affecting Front Suspension Geometry

The variables affecting the vehicle performance in the context of phenomena of steering are given below.

TABLE 1
INDEPENDENT AND DEPENDENT VARIBLES

Independent Variables	Dependent Variables
1. Length of Upper control arm	1. Kingpin angle
2. Length of Lower control arm	2. Camber angle
3. Length of Knuckle arm	3. Caster angle
4. Length of Fixed link	4. Toe angle
5. Diameter of wheel	5. Toe in
6. Mass of wheel	6. Toe out
7. Braker Height	7. Scrub radius
8. Braker Width	
9. Wheel linear velocity	
10. Operational time	
11. Acceleration due to gravity	
12. Clearance at spherical joint A	
13. Clearance at spherical joint B	
14. Clearance at revolute joint O1	
15. Clearance at revolute joint O2	
16. Lateral displacement	
17. Spindle length	

TABLE 2
PROCESS VARIBLES

Description	Symbol	Dimension
Upper control arm	Ua	$[M^0 L T^0]$
Lower control arm	La	$[M^0 L T^0]$
Knuckle arm	Ka	$[M^0 L T^0]$
Fixed link	Fi	$[M^0 L T^0]$
Diameter of wheel	Dw	$[M^0 L T^0]$
Weight of wheel	Wt	$[M L T^{-2}]$
Braker Height	Bh	$[M^0 L T^0]$
Braker Width	Bw	$[M^0 L T^0]$
Wheel velocity	Vt	$[M^0 L T^{-1}]$
Operational time	t	$[M^0 L^0 T]$
Acceleration due to gravity	g	$[M^0 L T^{-2}]$
Clearance at spherical joint A	Ca	$[M^0 L T^0]$
Clearance at spherical joint B	Cb	$[M^0 L T^0]$
Clearance at revolute joint O1	Co1	$[M^0 L T^0]$
Clearance at revolute joint O2	Co2	$[M^0 L T^0]$
Lateral displacement	Ld	$[M^0 L T^0]$
Spindle length	Sl	$[M^0 L T^0]$
Kingpin angle	Kga	$[M^0 L^0 T^0]$
Camber angle	Cm	$[M^0 L^0 T^0]$
Caster angle	Cs	$[M^0 L^0 T^0]$
Toe angle	Ta	$[M^0 L^0 T^0]$
Toe in	Ti	$[M^0 L T^0]$
Toe out	To	$[M^0 L T^0]$
Scrub radius	Sr	$[M^0 L T^0]$

M, L and T are the symbols for mass, length and time respectively using the dimensionless .
Caster angle

Cs = f (Ua, La, Ka, Fi, Dw, Wt, Bh, Bw, Vt, t, g, Co1, Co2, Ca, Cb, Ld, Sl) -----------(1)

General form can be defined as
ϕ (Ua, La, Ka, Fi, Dw, Wt, Bh, Bw, Vt, t, g, Co1, Co2, Ca, Cb, Ld, Sl, Kgp, Cs, Cm, Ta, Ti, To, Sr) = 0
21 dimensionless terms
$\phi(\pi1,\pi2,\pi3,\pi4,\pi5,\pi6,\pi7,\pi8, \pi9, \pi10, \pi11, \pi12, \pi13, \pi14, \pi15, \pi16, \pi17,\pi18,\pi19, \pi20, \pi21) = 0$
Choosing Ua, Vt and Wt as repeating variables
$\pi1$ = La / Ua
Similarly for other π terms are evaluate and dimensionless equations are formed
Caster angle:
Cs = f (La x Ka x Fi / Ua3 , Dw / Ua , Bh x Bw / Ua 2 , Vt x t / Ua , Ua x g / Vt2, Co1 x C02 x Ca x Cb / Ua 4, Ld x Sl / Ua 2)

3.2 Deduction of Generalized Experimental Data Based Models:

Classical experimentation was planned and carried out on the front suspension of an automobile for predicating steering behavior, to establish empirical relationships among the dependent π terms and independent π terms. The dependent and independent variables are defined in the Table 1. The dependent dimensionless ratios and Independent dimensionless ratios are as shown below.

TABLE 3
DIMENSIONLESS PI TERMS

Dimensionless ratios	Nature of basic Physical Quantities
π_1=La x Ka x Fi / Ua^3	Front suspension Link Lengths
π_2=Dw / Ua	Wheel Diameter
π_3=Bh x Bw / Ua^2	Braker width and height
π_4=Vt x t / Ua	Time of operation
π_5= Ua x g / Vt^2	Vehicle Speed
π_6=Co1 x C02 x Ca x Cb / Ua^4	Clearances at joints
π_7=Ld x sl / Ua^2	Displacement
π_{D2} = Cs	Caster angle

3.3 Formulation of Experimental Data Based Model

Each dependent π term is the function of the available independent π terms,
Cs = $f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7)$
Where,
Cs = π_{D1} , dependent pi term
Model of dependent pi term π_{D1}
Caster angle, Cs = $k_3 \times (\pi_1)^{a3} \times (\pi_2)^{b3} \times (\pi_3)^{c3} \times (\pi_4)^{d3} \times (\pi_5)^{e3} \times (\pi_6)^{f3} \times (\pi_7)^{g3}$
The values of exponents a_1, b_1, c_1, d_1, e_1, f_1, g_1 are established independently at a time, on the basic of data collected through classical experimentation. From these models values of all dependent pi terms are computed.

$$Cs = k_1 \times (\pi_1)^{a1} \times (\pi_2)^{b1} \times (\pi_3)^{c1} \times (\pi_4)^{d1} \times (\pi_5)^{e1} \times (\pi_6)^{f1} \times (\pi_7)^{g1} \quad (1)$$

$$Z = a + bX + cY + dZ + \ldots\ldots \quad (2)$$

The equation 1 can be brought in the form of equation 2 by taking log on both sides.

3.4 Model Formulation:

Model of dependent pi term π_{D1} for kingpin angle

$Cs = k_1 \times (\pi_1)^{a1} \times (\pi_2)^{b1} \times (\pi_3)^{c1} \times (\pi_4)^{d1} \times (\pi_5)^{e1} \times (\pi_6)^{f1} \times (\pi_7)^{g1}$

$\pi_{D1} = k_1 \times (\pi_1)^{a1} \times (\pi_2)^{b1} \times (\pi_3)^{c1} \times (\pi_4)^{d1} \times (\pi_5)^{e1} \times (\pi_6)^{f1} \times (\pi_7)^{g1}$

Taking log on the both sides of equation for π_{D1} ,getting eight unknown terms in the equations,

$\text{Log } \pi_{D1} = \log k1 + a_1 \log \pi_1 + b_1 \log \pi_2 + c_1 \log \pi_3 + d_1 \log \pi_4 + e_1 \log \pi_5 + f_1 \log \pi_6 + g_1 \log \pi_7$ -------(3)

Let,

$Z_1 = \log \pi_{D1},$ $K_1 = \log k1,$ $A = \log \pi_{1},$ $B = \log \pi_2$

$C = \log \pi_{3},$ $D = \log \pi_4,$ $E = \log \pi_{5},$ $F = \log \pi_6$

$G = \log \pi_7$

Putting the values in equations 3, the same can be written as

$Z_1 = K_1 + a_1 A + b_1 B + c_1 C + d_1 D + e_1 E + f_1 F + g_1 G$ (4)

X_1 matrix with K_1 and indices a_1, b_1, c_1, d_1, e_1, f_1, g_1 follows

$Cs = 1.020939 \times 10^{9} (\pi_1)^{104.05} (\pi_2)^{61.813} (\pi_3)^{0.0384} (\pi_4)^{65.836} (\pi_5)^{-0.236} (\pi_6)^{7.302} (\pi_7)^{0.88782}$

Thus corresponding to the dependent pi terms, models are formulated from the set of observed data for the response of caster angle. From these models values of the dependent pi terms are computed. The observed and computed values of the dependent pi terms are compared by calculating their mean values. In order to check the accuracy of the predicted / computed values of the dependent pi terms, error is worked out.

4 Analysis of Performance of the Model

The models have been formulated mathematically. An approximate generalized experimental data based models are evolved for predicating the Steering Behavior.

This includes application of Dimensional Analysis is quite simple way in which a given test can be made compact in operating plan. In this experimentation we may not be able to recognize all the variables that influence a test, but we should realize that they and their dimensional equation have reality whether or not it is apparent.

The indices of the model are the indicators of how the phenomenon is getting affected because of the interaction of various independent pi terms in the models. The influence of indices of the various independent pi terms on each dependent pi term is discussed below.

5. Comparison of computed values of experimental observation, experimental data based model and ANN simulation.

The comparison of the steering performance parameters by above three approaches is given below in Table 5

TABLE 5
VALUES OF DEPENDENT PI TERMS COMPUTED BY EXPERIMENTAL OBSERVATIONS, EXPERIMENTAL DATA BASED MODELS AND ANN SIMULATION

Sr. No.	Speed	Values calculated as per experimental observations							Values calculated as per experimental data based model							Values calculated as per ANN simulation						
		π_{D1}	π_{D2}	π_{D3}	π_{D4}	π_{D5}	π_{D6}	π_{D7}	π_{D1}	π_{D2}	π_{D3}	π_{D4}	π_{D5}	π_{D6}	π_{D7}	π_{D1}	π_{D2}	π_{D3}	π_{D4}	π_{D5}	π_{D6}	π_{D7}
1	5.23 cm / sec (Part I)	6.3154	0.245	1.17	0.24	59.895	120	120	6.01809	0.3611	1.1613	0.37325	60.0109	120.166	119.705	6.315	0.2457	1.1007	0.2371	59.894	120.076	119.972
2		6.65668	0.61183	2.105	0.549	59.738	119	121	6.40475	0.62494	2.08613	0.51818	59.7189	119.507	120.197	6.6573	0.6126	2.0151	0.5451	59.7375	119.218	120.913
3		6.80822	1.30686	4.204	0.918	59.442	119	121	6.66898	1.17455	4.16747	0.7937	59.4718	118.832	120.233	6.8084	1.3064	4.0826	0.908	59.4419	119.116	121
4		6.99313	2.08825	6.292	1.125	59.107	118	122	7.18687	1.74115	6.23507	0.95805	59.1803	118.288	121.102	6.9933	2.0883	6.3094	1.0992	59.1065	118.01	122.009
5		7.20417	2.1206	7.445	1.131	59.093	118	122	7.39292	2.05037	7.38256	1.04048	59.0674	118.069	121.416	7.2052	2.1211	7.4459	1.1196	59.0923	118.003	122.004
6		7.47033	2.87391	8.592	1.236	58.77	118	122	7.5142	2.34886	8.53154	1.1271	58.9937	117.906	121.554	7.4742	2.8743	8.5829	1.207	58.7725	118.003	121.983
7	7.17 cm / sec (Part II)	5.93264	0.46765	1.871	0.438	59.8	120	120	6.27075	0.67942	1.85772	0.58871	59.7849	121.825	121.886	5.9361	0.4691	1.8478	0.4336	59.7951	120.011	119.999
8		6.61918	1.25473	2.806	0.898	59.463	119	121	6.65972	1.00013	2.78091	0.72315	59.5341	121.312	122.52	6.6174	1.2513	2.792	0.8722	59.4667	119.034	120.981
9		7.03646	1.62515	4.902	1.02	59.305	119	121	6.92387	1.66957	4.86095	1.01269	59.3171	120.74	122.655	7.0357	1.6235	4.9043	1.0018	59.3051	118.991	120.992
10		7.20364	2.16884	6.754	1.139	59.072	118	122	7.4545	2.29976	6.69535	1.15639	59.0444	120.256	123.603	7.2084	2.1686	6.7777	1.096	59.0761	117.994	121.991
11		7.63478	2.27007	7.445	1.156	59.029	118	122	7.66194	2.54171	7.38077	1.19707	58.9473	120.095	123.977	7.6651	2.2699	7.5239	1.1357	59.0275	117.99	122.027
12		7.81963	3.08839	8.821	1.258	58.678	117	123	7.79001	2.98149	8.76002	1.32015	58.868	119.906	124.098	7.8678	3.0883	8.8361	1.2445	58.6755	117.007	123.022
13	10.31 cm / sec (Part III)	6.38349	0.79478	1.17	0.672	59.66	119	121	6.56097	0.54205	1.16032	0.46661	59.7432	119.805	120.657	6.3948	0.7911	1.1586	0.6985	59.6653	118.977	120.991
14		6.98616	1.89226	3.505	1.085	59.191	118	122	7.02349	1.47644	3.4741	0.91273	59.3403	118.723	120.782	6.9845	1.8872	3.4939	1.0667	59.1836	117.972	121.993
15		7.52561	2.3214	5.829	1.164	59.007	118	122	7.29799	2.36021	5.78342	1.237	59.1346	118.203	120.95	7.5243	2.3196	5.8188	1.1487	59.0024	118.006	121.99
16		7.71226	2.48823	6.985	1.189	58.935	118	122	7.84466	2.86995	6.92203	1.28545	58.8933	117.846	121.987	7.7401	2.488	6.998	1.1886	58.9375	118.023	122.001
17		8.02771	2.79989	8.592	1.228	58.802	118	122	8.07325	3.50127	8.52894	1.43386	58.7723	117.596	122.275	8.0609	2.7999	8.666	1.2214	58.8108	117.999	122.001
18		8.74739	3.24134	9.277	1.272	58.613	117	123	8.19937	3.77861	9.21551	1.48471	58.7136	117.489	122.463	8.7137	3.2412	9.4223	1.2629	58.622	117.015	122.994

5 CONCLUSION

Table shows the steering performance parameters computed by experimental observations, experimental data based model and ANN simulation

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