Study on Simulation of on-Center Handling Tests

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Abstract

This paper describes a simulation of on-center handling test, in which a linear 3 degrees of freedom vehicle handling model and a power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration. The cross plots of steering wheel angle-lateral acceleration, steering wheel torque-lateral acceleration, steering wheel torque-steering wheel angle, steering worklateral acceleration, and steering work gradient-lateral acceleration are drawn and all the oncenter handling parameters are determined from them. The simulation results are compared with the data presented in the literatures, which indicates that the simulation results are reasonable.

Index terms— on-center handling test; simulation; vehicle handling model; power steering system model; time history; steering wheel angle; steering wheel torque; l

orman (1984) described how to do on-center handling test in detail. On-center handling test has been widely used to measure handling characteristics observed by a car driver during normal highway and freeway driving. It is also one of the essential tests used by car and its steering system manufacturers to quantify the performance of steering systems. The simulation of on-center handling test can help them determine the appropriate system parameters combination to make a car have good on-center handling characteristics.

There have been some papers published, in which the methods for simulating on-center handling tests are introduced. Post et al. **??**1996) and Kim (1997) described different simulation methods but they didn't present all the on-center handling cross plots and determine all the on-center handling parameters necessary for characterizing vehicle's on-center handling performance prescribed by Norman (1984).

This paper describes a simulation of on-center handling test, which is based on the test procedure presented by Norman (1984). A linear 3-dof (degrees of freedom) vehicle handling model and a power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration. The cross plots of steering wheel angle-lateral acceleration, steering wheel torque-lateral acceleration, steering wheel torquesteering wheel angle, steering work-lateral acceleration, and steering work gradient-lateral acceleration are drawn and all the on-center handling parameters are determined from them. Fig. 1 shows the main modules of the simulation program.

Input: reference steer angle of vehicle front wheels Output: on-center handling cross plots and parameters

1 3-Dof Vehicle Handling Model

A linear 3-dof vehicle handling model is adopted in the simulation because the peak lateral acceleration is limited to about 0.2g in the on-center handling tests as prescribed by Norman (1984). This ref s f ? ? u r a ? u ? ? + ? + ? = (1) r r ? u r b ? u ? ? ? ? ? ? = (2) f f f f y ? C C F ? ? + ? ? ? = ? ? ? 2 2 1 (3)C F ? ? + ? ? ? = 2 2 2 ? (4) 2 2 , 1 f T nf uf y yf ?f s A E r) u r a (u -m F E ? -E ? ? ? ? + ? + ? ? ? + ? = ? ? ? (5) f f f f T N N A ? ? ? ? ? ? + ? ? = 2 2 , (6) 2 2 , 1 f T nf uf y yf ?f f A r) u r a (u -m F ? ? Î?" + ? + ? + ? ? ? Î?" ? ? Î?" = ? ? ? ? (7) 2 2 , 2 r T nr ur y yr ?r r A E r) u r b (u -m F E ? -E ? ? ? ? + ? ? ? ? ? + ? = ? ? ? (8) r r r r T N N A ? ? ? ? ? ? + ? ? = 2 2 , (9) 2 2 , 2 r T nr ur y yr ?r r A r) u r b (u -m F ? - ? Î?" ? ? + ? ? ? ? ? Î?" + ? Î?" = ? ? ? ? (10)

rear tires lateral force; C ?f , C ?r -front, rear tire cornering stiffness; ? f , ? r -front, rear tire inclination angle; C ?f , C ?rfront, rear tire camber stiffness; E ?f , E ?r -front, rear roll steer coefficient; E yf , E yr -front, rear lateral force compliance steer coefficient; E nf , E nr -front, rear aligning torque compliance steer coefficient; m uf , m ur -front, rear unsprung mass; A T,f , A T,r -front, rear tires aligning torque; N ?f , N ?r -front, rear tire aligning torque stiffness; N ?f , N ?r -front, rear tire aligning torque stiffness due to camber; Î?” ?f , Î?” ?r -front, rear roll camber coefficient; Î?” yf , Î?” yr -front, rear lateral force compliance camber coefficient; Î?” nf , Î?” nr -front, rear aligning torque compliance camber coefficient; h f , h r -front, rear roll center height; h uf , h urfront, rear unsprung center of gravity height; m s -vehicle sprung mass; ? -roll axis inclination in side view; h s -distance from sprung center of gravity to roll axis; K ?f , K ?r -front, rear suspension roll stiffness; C ?f , C ?r -front, rear suspension roll damping; a ys -lateral acceleration of sprung center of gravity. The equations of motion for the vehicle model are derived as follows, in which ? is assumed to be zero for simplicity because it's usually small:2 1) (y y s s a F F h m r u u m + = ? ? + ? + ? ? ? ? ? ? ? ? (11) r T f T y y xzs z A A F b F a I r I , , 2 1 + + ? ? ? = ? ? ? ? ? ? ? ? (12) ? ? ? ? ? ? + ? ? ? ? ? ? = + ? ? ? + ? ? ? ? ? ? ? ? ? ? ? ?) ( ) ( ) (r f r f s s s s xzs xs C C K K h g m r u h m r I I (13)

where, m a -vehicle total mass; I z -vehicle total yaw inertia; I xzs -sprung roll-yaw product; Ixs -sprung roll inertia; g -gravitational acceleration. Table **??** shows the values of the vehicle model parameters used in the simulation. Z r U] , , , [? ? ? ? ? ? ? ? ? = (16)

The equations (**??**1), (12), and (13) can be written in the matrix form with? ref as the input:ref N U R U M ? ? + ? = ? ? (17)

where, M, R -4×4 matrix; N -4×1 matrix.

Equation (**??**7) is changed into equation (**??**8) by multiplying M -1 on both sides of it:ref N M U R M U ? ? ? + ? ? = ? ? ? 1 1 (18)

Equation (**??**8) is solved with Runge-Kutta numerical integration method. In the simulation, the formula of ? ref is) 2 sin(t f H A ref ref ? ? ? ? = ? ? ? (19)

where, ? refA -amplitude of ? ref ; f H -frequency. Fig. 3 In order to obtain the on-center handling characteristics, the steering wheel rotation angle and torque have to be determined. A model of the steering system is constructed to determine them.

2 III. Model of the Steering System

It is assumed that the vehicle studied is a rear drive vehicle equipped with a power integral steering gear and the inertia forces and moments of all parts in the steering system can be neglected. Fig. **??** shows the model of the steering system. The formula for the kingpin aligning torque A T,k isref n f y d f T k T r W F r A A ? = sin cos cos sin cos cos 1 , ,**(21)**

) cos (? ? ? ? = ? tg arctg (22) ? ? ? ? + ? = cos) (s d n r tg r r (23)

where, ? -caster; ? -kingpin inclination angle; r s -kingpin off-set; r d -radius of front tire; f W -vertical load on front axle; camber is assumed to be zero.

Fig. **??** shows the section view of the valve body and valve spool in their assembled position as well as the valve equivalent flow paths.

When the vehicle's engine is running, the flow Q T from the power steering pump gets into the four axial supply grooves F on the inside diameter of the valve body through the four supply holes E. Then, the flow diverts into two parts, Q L and Q R :) (2 Q 1 A P q R P P A C ? ? ? ? = (24) ? A q R A P A C ? ? ? = + 2 Q Q 2 (25) ?) (2 Q 1 B P q L P P B C ? ? ? ? = (26) ? B q B L P B C ? ? ? = ? 2 Q Q 2 (27) R L T Q Q Q + = (28) B A Q Q = (29)

where, the pressure at the center of the spool is assumed to be zero; the leakage in the gear is neglected; P P -pump pressure; P A , P B -pressure at the groove G R1 ,G L1 ; C q -flow coefficient of the valve gaps; ? -fluid density.

A power integral steering gear was taken apart and its valve geometry was measured. Fig. 6(a) shows the areas of A 1 , A 2 , B 1 , and B 2 versus the rotational angle of the spool relative to the valve body. Let P DIFF be the pressure differential across the cylinder piston, thus L L R k = (31)

The steering gear applies a torque T g to balance A T,k ,k k T g R A T ln , ? = (32)

Let the over-center turning torque of the integral steering gear be T fo when T g is zero and the steering ratio of the gear be G R . T fo is assumed to be a dry friction torque. It can be equivalent to a dry friction torque T fg acting on the gear sector, So, the equations (**??**7) and (**??**2) can be written as a general form, **??**6) can be written as Let the piston velosity be Vp and the flow to the hydraulic cylinder be Q A , Table **??** shows the values of the parameters used in the steering system model. Fig. **??** shows the time histories of pressure differential P DIFF and T-bar torsional angle T ? . Fig. **??** shows the time histories of sw ? , sw T , and lateral acceleration a y (r u ?). On-center handling cross-plots (as shown in Fig. 10) are drawn from the time histories shown in Fig. **??** and the on-center handling parameters (as shown in Table 3) are obtained from the cross-plots by using the methods described by Norman (1984). The effects of changing the values of the vehicle and its steering system parameters on the on-center handling characteristics can be studied with the simulaion, which helps to find the appropriate system parameters combination to make a car have good oncenter handling characteristics. For example, if only Q T (flow from the power steering pump to the steering gear) is changed from 9.992 L/m to 4.996 L/m, with all other parameters kept unchanged, in the above simulation, the new simulation results are shown in Fig. 11 In the simulation of on-center handling test, a simple linear 3-dof (degrees of freedom) vehicle handling model and a comprehensive power integral steering system model are incorporated to calculate the time histories of steering wheel angle, steering wheel torque, and vehicle lateral acceleration, from which the on-center handling cross-plots and parameters are obtained. The linear 3-dof vehicle handling model can give sufficiently accurate simulation results in the lateral acceleration range (peak value is about 0.2g) of the oncenter handling tests. Because the rotation angle amplitude and frequency of the steering wheel are small, the inertia forces and moments of all parts in the steering system can be neglected, which makes the steering system model much simpler. Compared with the data presented in the literatures, the simulation results obtained are reasonable. So the simulation can be useful in finding the appropriate system parameters combination to make a car have good on-center handling characteristics.g k ref P r R dt d V ? ? = ln) (? (49) p P np A A V s ? ? = Q (50) ? ? ? ? + = S3. from sign different has V hen [1] [2] [3]

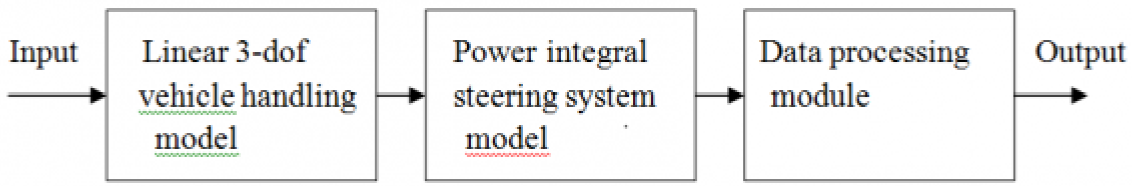

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Figure 1: Fig. 1 :

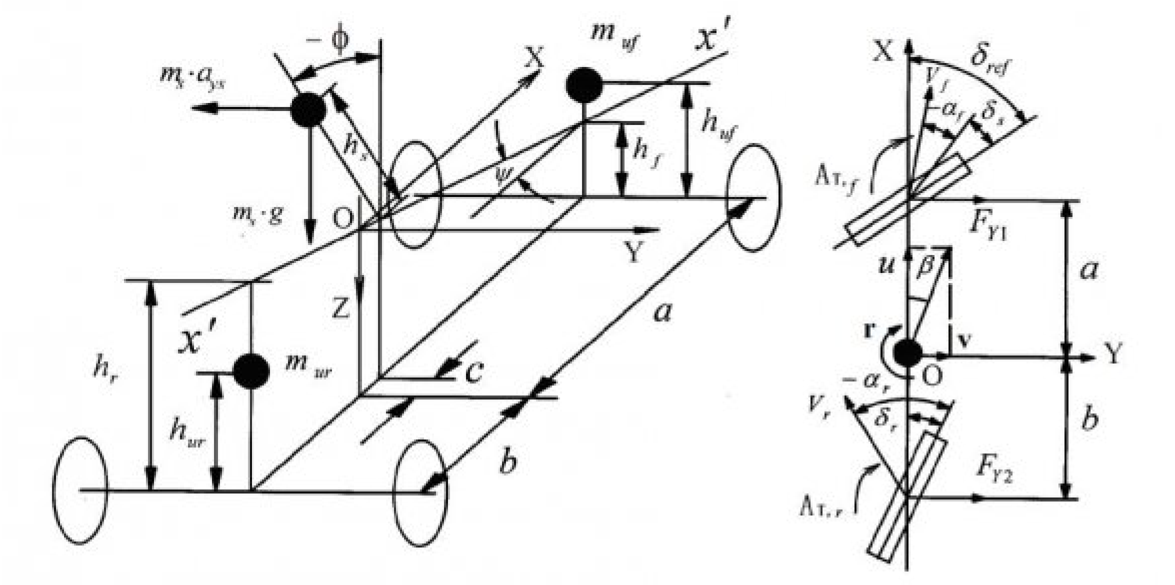

Figure 2:

[1] © 2016 Global Journals Inc. (US) h s = 385.11mm -distance from sprung center of gravity to roll axis;
[2] B© 2016 Global Journals Inc. (US)
[3] © 2016 Global Journals Inc. (US)

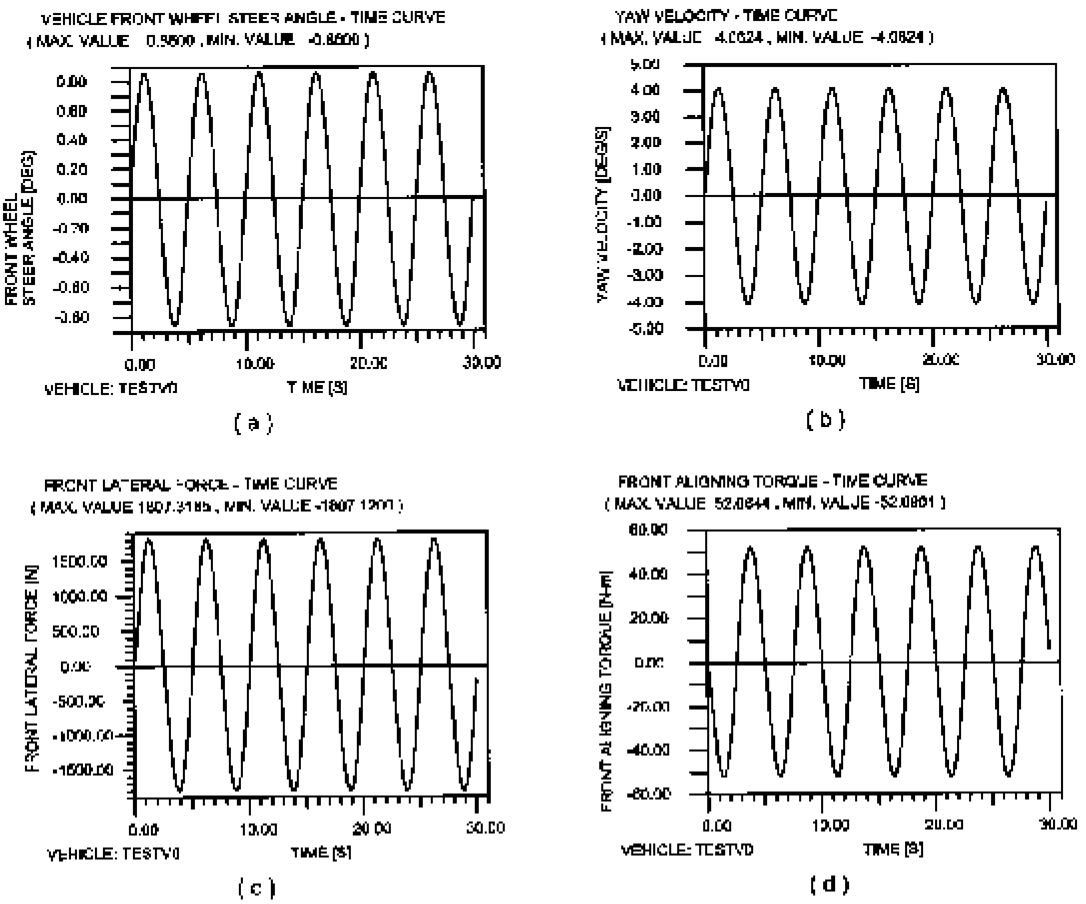

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Figure 3: Fig. 2 :

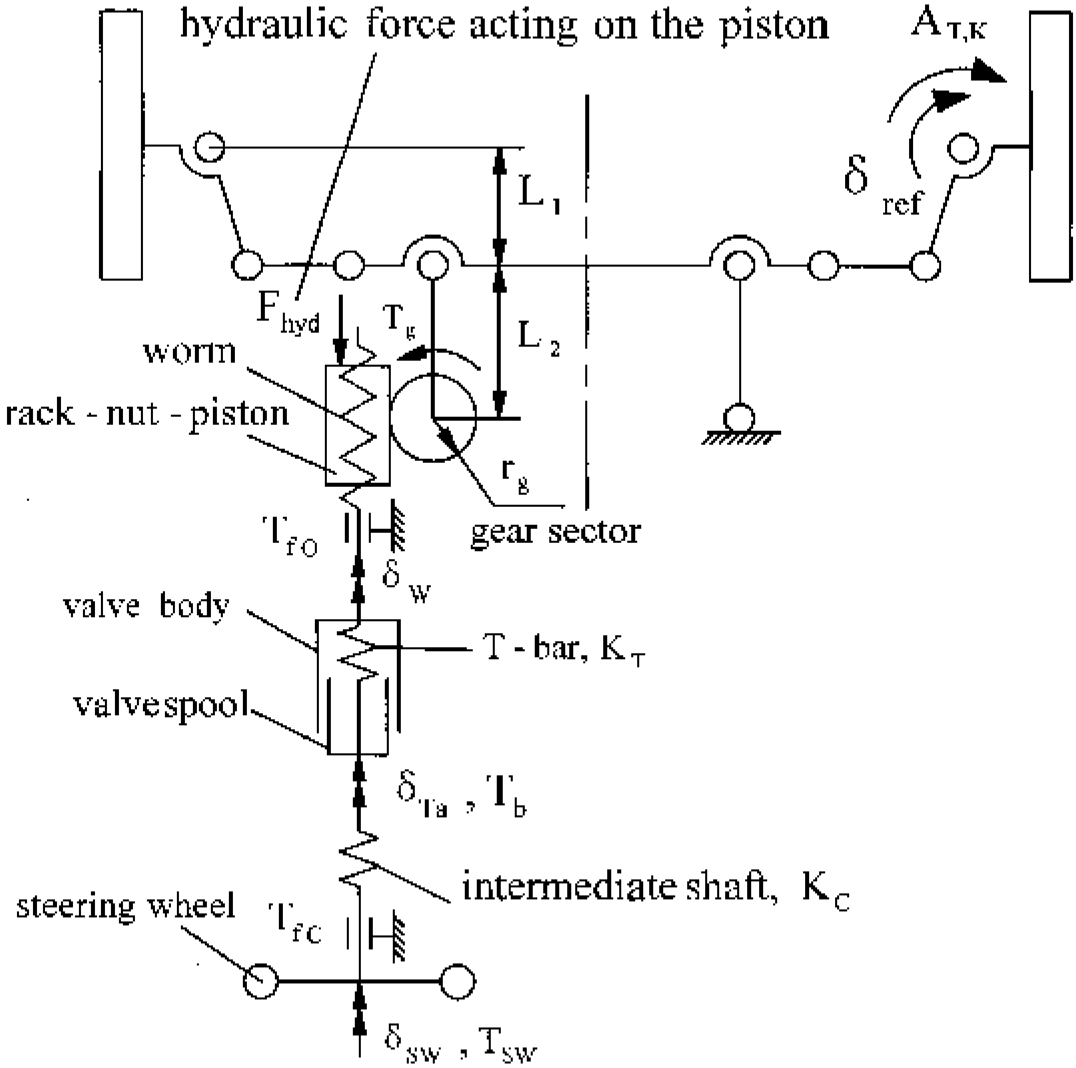

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Figure 4: Table 1 :

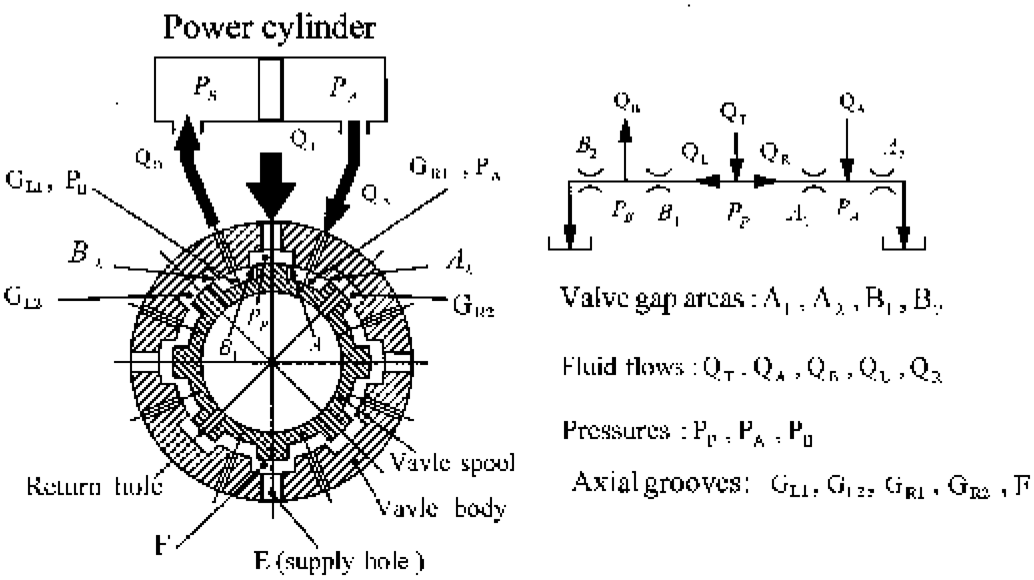
Power cylinder
Valve gap areas : A1 , A2 , B1 , B2
Fluid flows : QT , QA , QB , QL , QR
Pressures : PP , PA , PB
Axial grooves: GL1, GL2, GR1 , GR2 , F
Return hole
Vavle spool
Vavle body
E (supply hole)

Figure 5:

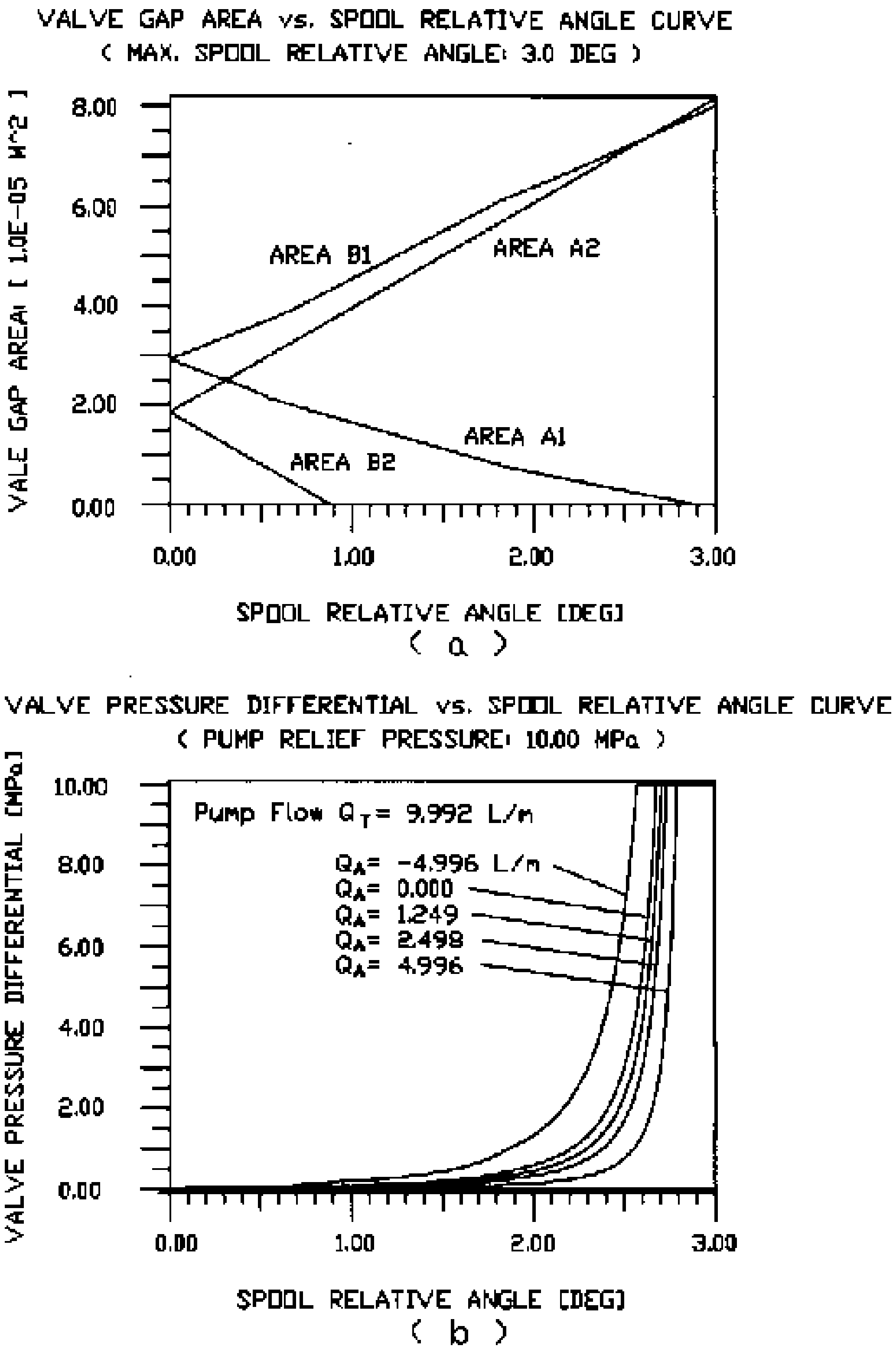

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Figure 6: Fig. 3 (

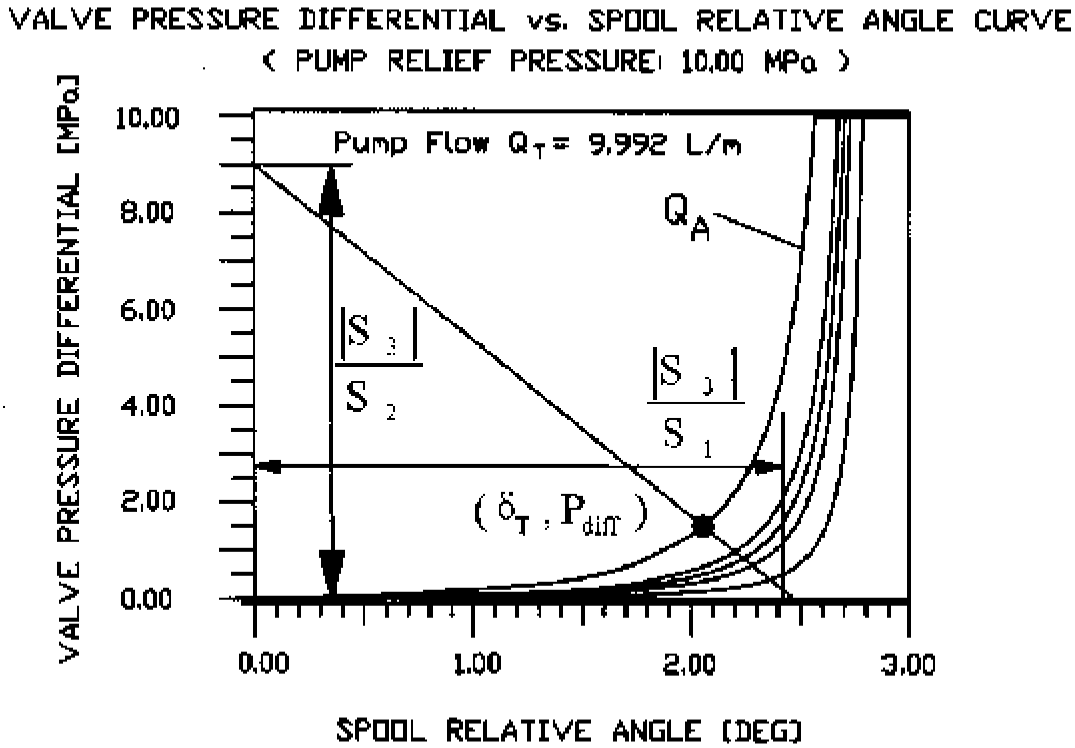

Figure 7:

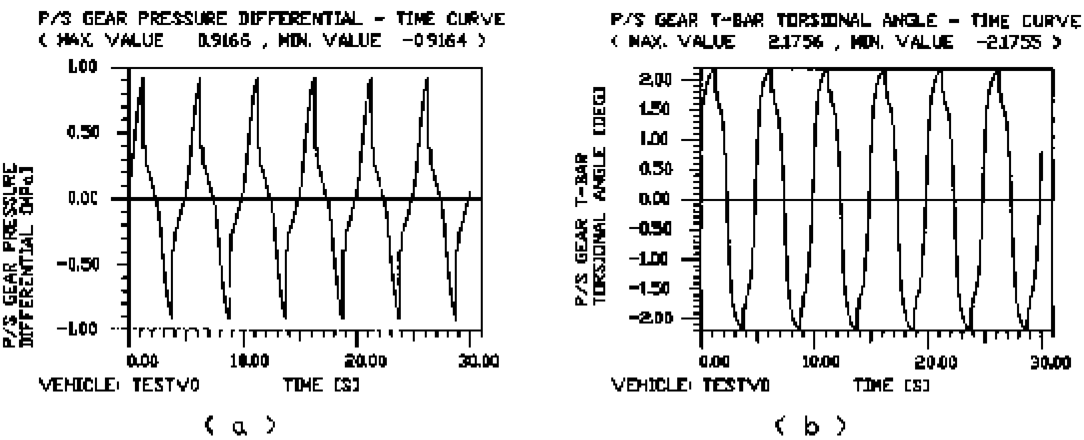

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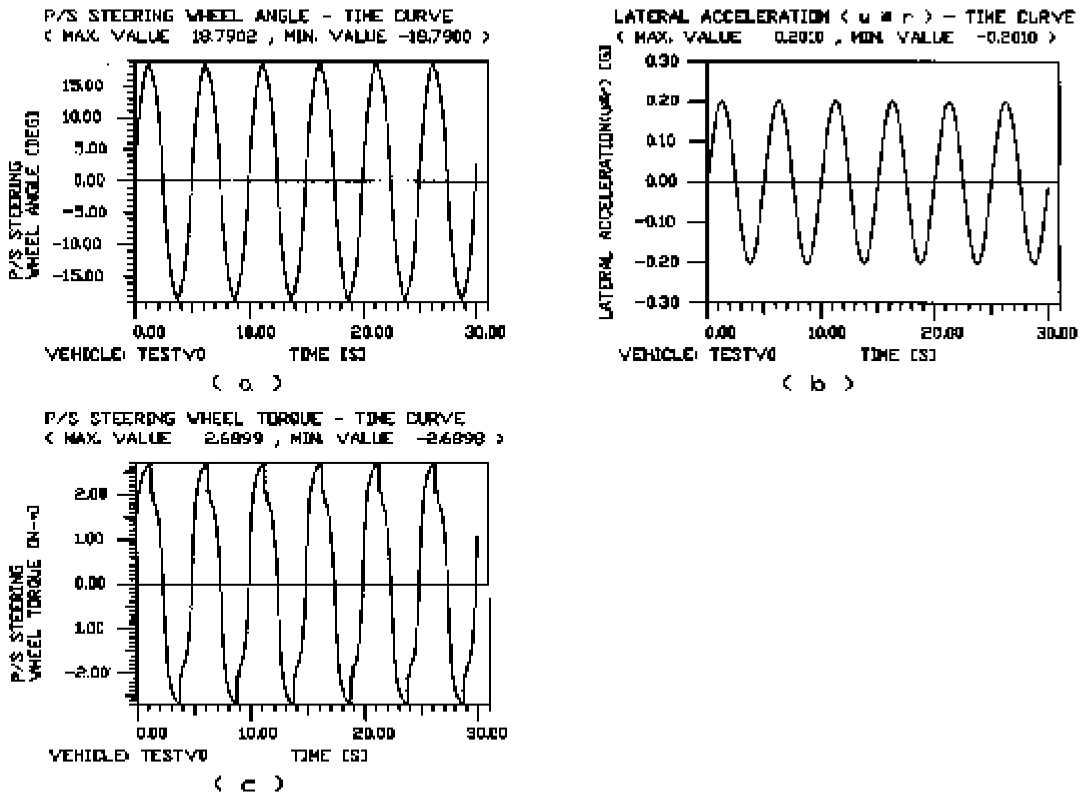
Figure 8: 1)Fig. 4 :



P/S STEERING WHEEL ANGLE - TIME CURVE
(MAX. VALUE 18.7902 , MIN. VALUE -18.7900)
P/S STEERING WHEEL ANGLE [DEG]
VEHICLE: TESTV0
TIME [S]
(a)
LATERAL ACCELERATION (u * r) - TIME CURVE
(MAX. VALUE 0.2010 , MIN. VALUE -0.2010)
LATERAL ACCELERATION(u*r) [G]
VEHICLE: TESTV0
TIME [S]
(b)
P/S STEERING WHEEL TORQUE - TIME CURVE
(MAX. VALUE 2.6899 , MIN. VALUE -2.6898)
P/S STEERING WHEEL TORQUE [N-M]
VEHICLE: TESTV0
TIME [S]
(c)

Figure 9:

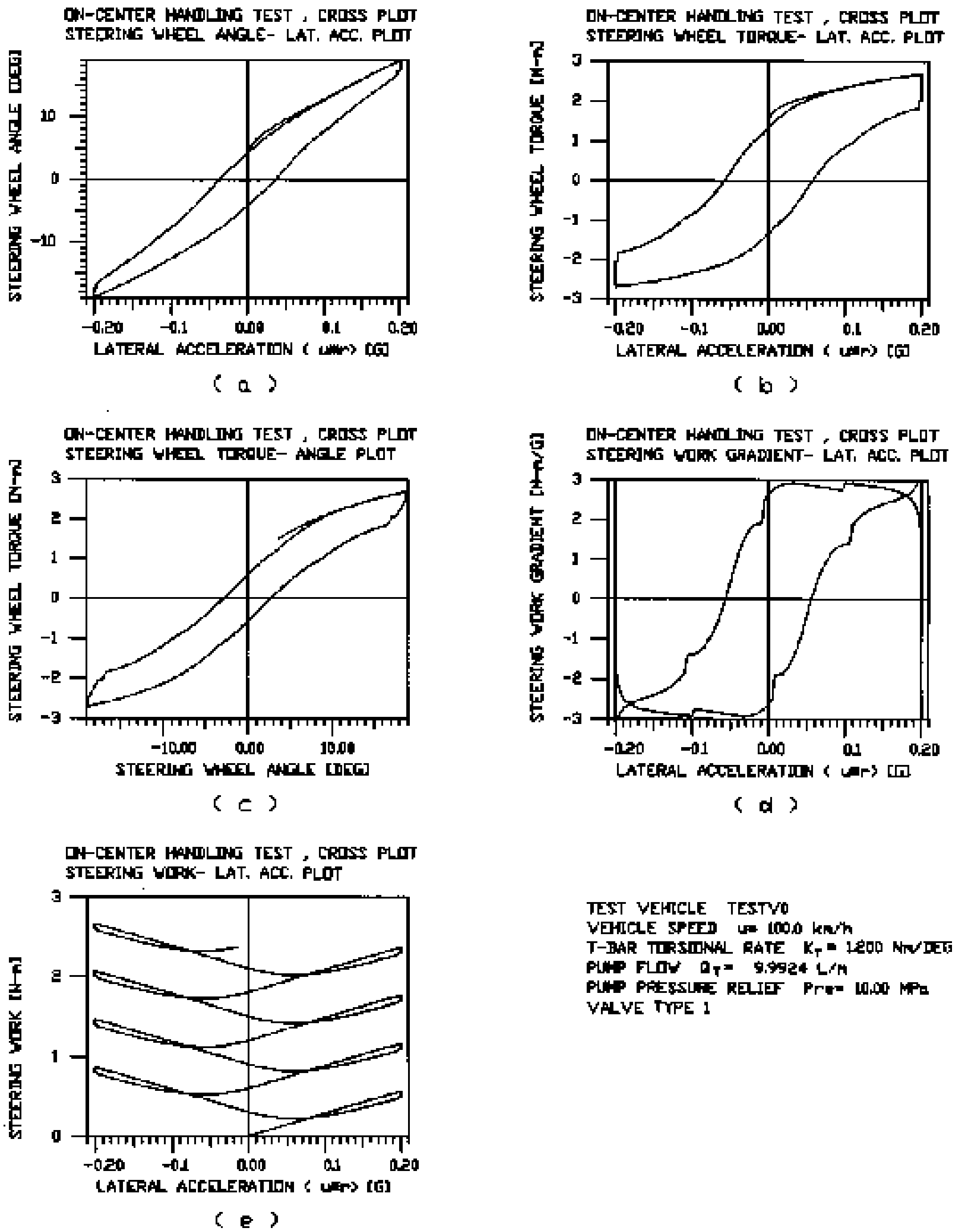


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Figure 10: Fig. 6 (

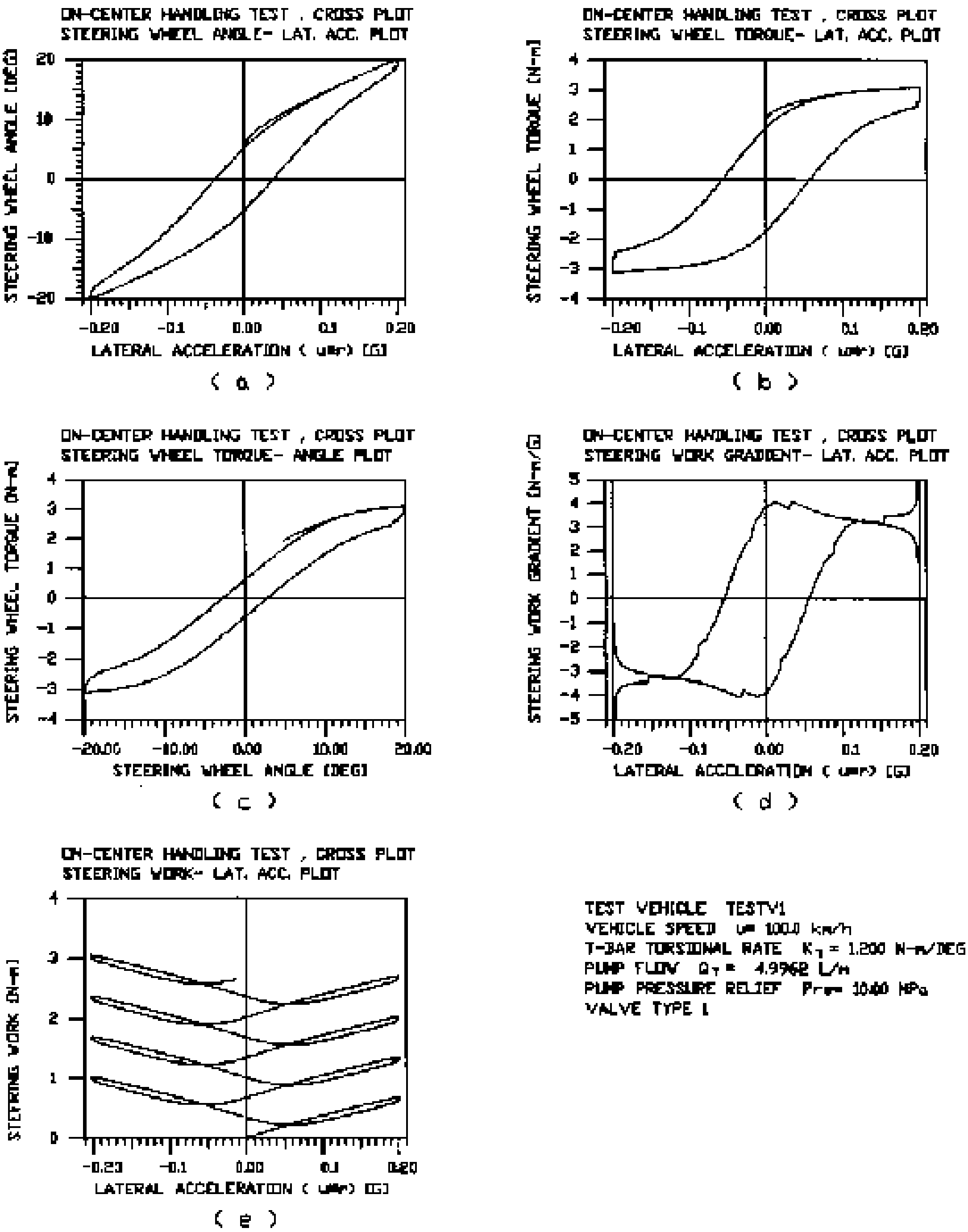

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Figure 11: Fig. 5 :Fig. 6 :

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Steering sensitivity at 0.1g (g's/100deg SW) : 1.40
Minimum steering sensitivity (g's/100deg SW) : 0.72
Steering sensitivity ratio: 0.52
Steering hysteresis (deg SW): 6.95
Steering torque at 0.0g (Nm): 1.34
Steering torque gradient at 0.0g (Nm/g): 20.64
Steering torque at 0.1g (Nm): 2.34
Steering torque gradient at 0.1g (Nm/g): 5.54
Steering torque gradient ratio: 0.27
Lateral acceleration at 0.0Nm (g's): -0.057
Steering torque at 0.0deg SW (Nm): 0.63
Steering torque gradient at 0.0 deg SW (Nm/deg): 0.21
Steering work sensitivity (g 2 /100Nm): 4.3

Figure 12: Table 3 :

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Figure 13: Table 4 .

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Figure 14: Table 4 :

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