

Investigation of Alleged Loss of Power Steering in 2004 Chevrolet Malibu Vehicles

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16. Abstract <p>These vehicles are equipped with Electronic Power Steering (EPS) as standard equipment. The manufacturer of the EPS has acknowledged that a loss of power steering can occur as a result of an EPS signal loss. When a signal loss is detected, the Power Steering Control Module (PSCM) disables the EPS until the next ignition cycle.</p> <p>The objectives of this program were 1) to determine the steering effort required by the driver during various driving maneuvers with the EPS both enabled and disabled; 2) to determine the time required for the system to default to manual steering (ramp-down time) when a fault is detected in the EPS; and 3) to determine whether or not the EPS could malfunction in a manner that removes directional control of the vehicle from the driver.</p> <p>Results of the testing showed that none of the four subject vehicles (including two complaint vehicles) tested during this program exhibited a loss of power steering assist unless it was artificially induced.</p> <p>The greatest steering effort encountered during testing with nonfunctional EPS was approximately 26 lb-ft during a 360° left turn at 8-mph. When performed with functional EPS, this same maneuver required only approximately 4 lb-ft. The change in effort from assisted to non-assisted force levels ranged between 0.4 and 1.6 seconds when the EPS became disabled. Two visual warnings and one audible warning were provided to the driver simultaneously with a loss of power steering assist.</p> <p>Previous studies suggest that small (5th-percentile) drivers may have difficulty trying to steer the subject vehicle when power assist is lost. Drivers of this stature may describe the steering as "locked" if a loss of power assist was encountered.</p>			
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1.0 Introduction

This program was performed at the Vehicle Research and Test Center (VRTC) at the request of the Office of Defects Investigation (ODI) of the National Highway Traffic Safety Administration (NHTSA). ODI opened an Engineering Analysis (EA04-018) on 2004 Chevrolet Malibu vehicles. ODI has received complaints on the subject vehicles concerning a loss of power steering without warning that makes the vehicles difficult to steer.

2.0 Background

Subject vehicles are equipped with an Electric Power Steering system (EPS). This system uses an electric motor, mounted to the steering column, rather than the more traditional hydraulic-pump method, to provide power steering assistance. Sensors within the steering column detect steering wheel position and input torque. The amount of power assistance that is applied through the power steering motor is based on the output of both of these sensors and the vehicle speed. Figure 1 shows the upper portion of the steering column with the assist motor mounted to it.

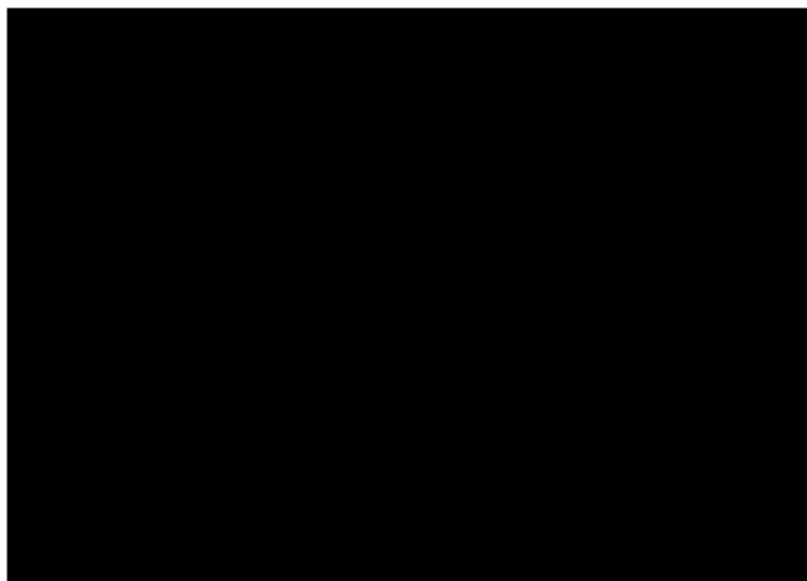


Figure 1
Steering Column with EPS

Delphi, the manufacturer of the EPS, has acknowledged that the loss of power steering can occur and has identified two problems that can contribute to the failure mode: 1) Steering column assembly grease may degrade and seep into the sensors, thus contaminating the circuit board

contacts and brushes, and 2) insufficient gold plating of the torque and position sensor contacts may allow premature wear of the slip ring and electrical noise. Delphi claims that either problem may cause a signal loss to occur. GM has issued Service Bulletins 04006B (dated 12/3/04) and 04050A (dated 12/15/04) regarding loss of power steering assist.

Information furnished by GM for this investigation states that when a signal loss of 30 ms or longer is detected, the Power Steering Control Module (PSCM) disables the EPS until the next ignition cycle. VRTC was not able to verify the 30-ms time period but was able to verify that when there was a loss of signal, the EPS became disabled until the next ignition cycle.

The EPS torque sensor has two output signals. When the sensor detects torque input to the steering wheel, one output signal increases from a low value to a high value while the other output signal decreases from a high value to a low value. Using two output signals provides a safety redundancy and allows the system to self-check itself.

3.0 Objective

The objectives of this program were 1) to determine the steering effort required by the driver during various driving maneuvers with the EPS both enabled and disabled; 2) to determine the time required for the system to default to manual steering (ramp-down time) when a fault is detected in the EPS; and 3) to determine whether or not the EPS could malfunction in a manner that removes directional control of the vehicle from the driver.

4.0 Procedure

The following activities were undertaken for this project:

4.1 Complaint Vehicle Testing

Two complaint vehicles were leased for testing at separate times. Instrumentation was installed to record steering wheel angle, steering wheel input torque, and vehicle speed. Instrumentation is described in Appendix I.

4.1.1 Complaint Vehicle #1 - VIN: 1G1ZU54834

The owner of the first complaint vehicle tested claimed that power steering assist was lost on two occasions within three days. In one case, the operator claimed to have been driving on an interstate highway at speeds of 75-80 mph for approximately one hour and was slowing down for a tollbooth

when the loss of assist allegedly occurred. In the other case, the operator claimed to have been driving in stop-and-go city traffic for approximately one hour when the loss of assist allegedly occurred.

Testing of the first complaint vehicle consisted of performing the maneuvers described below while recording the data using the instrumentation noted in Section 4.1. Each maneuver was repeated several times over a 5-day test period with varying onset rates of the maneuver, both with the EPS operational and with the source of electrical power for the EPS disconnected to simulate a failed condition. In each case, the vehicle was driven for at least 1 hour prior to testing to simulate the complaint time interval. The test maneuvers included:

1. Low-speed (less than 10 mph) parking lot maneuvers consisting of full-lock left and right turns.
2. Slow-speed (10 – 30 mph) driving maneuvers consisting of intersection-type turns and S-turns.
3. High-speed (50-70 mph) driving maneuvers consisting of lane changes and gradual turns, with and without light-to-moderate brake applications.

4.1.2 Complaint Vehicle #2 – VIN: 1G1ZT54894F

The owner of the second complaint vehicle claimed that on a few random occasions, the steering wheel would oscillate left and right a few inches with no driver input and that normal operation returned when the engine was turned off and then restarted. The owner claimed that a total loss of assist never occurred.

Testing of the second complaint vehicle occurred over several days with varying weather conditions. Testing consisted of initially gathering data while performing a limited number of the driving maneuvers described in Section 4.1.1 to show consistency with other vehicles tested during this program. This was followed by repeated cycles of driving an 8.8-mile test loop at relatively low speeds without gathering data. The test loop consisted primarily of stop-and-go driving on two-lane roads near VRTC to simulate suburban driving conditions. Because the owner had stated that the oscillating of the steering wheel usually occurred first thing in the morning, the vehicle was also tested on the same test loop from a cold start after being parked outside overnight when the minimum temperature reached 28°F.

4.2 Subject Vehicle Testing

Two subject vehicles were leased at separate times. The original steering column was removed from each vehicle and a steering column that was provided by General Motors (GM) was installed in its place. The replacement steering column had allegedly been returned under GM's warranty program as exhibiting a loss of power steering assist. Prior to testing, instrumentation was installed in each as described in Section 4.1 above and additional wiring was installed on the replacement steering column that allowed the monitoring of the sensor input and output signals.

4.2.1 Subject Vehicle #1 – VIN: 1G1ZU548X4E

Driving tests were performed to simulate a sensor failure in order to determine ramp-down time after an EPS failure occurred. A push-button switch was installed in both of the torque-sensor output circuits so that a momentary loss of signal could be initiated in either circuit at will. With the switches installed, the vehicle was driven through a limited number of the maneuvers described in Section 4.1.1 while the output signal from each torque sensor was, in turn, momentarily interrupted.

Static testing was also performed, with and without the engine running, during which one of the torque sensor output signals was artificially held constant using an external voltage supply while the other torque sensor output signal was allowed to change normally when the steering wheel was turned. The amount of torque required to cause the EPS to detect this fault was then measured.

4.2.2 Subject Vehicle #2 – VIN: 1G1ZU64814

Static testing was performed, with and without the engine running, to determine whether the EPS could cause the steering to "pull" in either direction and, if so, how much. Using the vehicle's OBD II diagnostic interface, the EPS was intentionally miscalibrated with the maximum offset torque value that the PSCM would allow. This condition caused the EPS to rotate the steering wheel to full lock. The amount of torque required to hold the steering wheel stationary against the offset torque calibration in a straight-ahead position was then measured using the installed instrumentation. The vehicle was also driven briefly and slowly in order to determine the effect on vehicle control of a miscalibrated torque sensor.

5.0 Results

The results of each testing activity listed in the previous section are presented below.

5.1 Complaint Vehicle #1

Tabulated test results from Complaint Vehicle #1 are presented in Appendix II. With normal EPS operation, the range of steering wheel torque values with the vehicle in motion was found to be 0.9 lb-ft (Test 17) to 3.7 lb-ft (Test 16). Higher steering wheel torque values were also measured during slow speed and static conditions. A value of 9.9 lb-ft (Test 36) was measured with the vehicle stationary and a value of 6.2 lb-ft (Test 30) was measured during a 7-mph full-lock left turn, but only after the steering wheel had reached full lock. Both of these conditions were considered to be irrelevant. The static reading was considered a reference only since vehicle directional control was not an issue with the vehicle stationary. The full-lock reading was considered to be misleading because the maximum torque value occurred after the steering system reached full lock.

This complaint vehicle was driven daily for five days during which an unintentional loss of power steering assist never occurred. The EPS was subsequently disabled intentionally by removing the EPS fuse. With the EPS disabled, the range of steering wheel torque values with the vehicle in motion was found to be 5.5 lb-ft (Test 96) to 26.3 lb-ft (Test 105). With the EPS disabled, a torque of 37.5 lb-ft (maximum effort the driver could exert) was measured while turning the steering wheel with the vehicle stationary (Tests 131 and 132). As noted previously, when performed with the EPS enabled, this maneuver required only 9.9 lb-ft.

5.2 Complaint Vehicle #2

Tabulated test results from initial testing of Complaint Vehicle #2 during the maneuvers described in Section 4.1.1 are presented in Appendix III. Torque values measured with a functional EPS during these maneuvers ranged from 2.9 lb-ft (Test 1) to 4.6 lb-ft (Test 7). These values were slightly higher than those measured on Complaint Vehicle #1 but were still considered to be normal. No loss of power steering assist was noted during these maneuvers nor during the testing on the 8.8-mile slow-speed test loop. The EPS was not tested in the disabled mode because of time and mileage limits agreed upon in the lease.

5.3 Subject Vehicle #1

Tabulated test results from testing of Subject Vehicle #1 are presented in Appendix IV. No loss of power steering assist was noted during the initial four days of testing with the GM "complaint" steering column.

Following the four days of testing with normal EPS operation, testing was performed while each of the torque sensor output signals was momentarily interrupted. Each time the signal was interrupted, the EPS detected the fault and the power assist was lost virtually instantaneously. This loss was noted by the "wrench" light being illuminated on the instrument panel, by the "power steering" message being displayed on the information panel, and by a warning "chime" being sounded. In the worst case (Test 13) found during this in-motion testing, the measured torque value increased from approximately 2.7 lb-ft to approximately 22.5 lb-ft during a low-speed driving maneuver. The period of time over which the steering effort increased from assisted levels to unassisted levels varied between 0.4 and 1.6 seconds.

In the static tests described in Section 4.2.1, the PSCM detected the induced fault and the EPS reverted to manual steering mode when the torque reached approximately 7 lb-ft.

Upon completion of testing, the original steering column was reinstalled into the subject vehicle and the computer was cleared of all fault codes before the vehicle was returned to the dealership from which it was leased.

5.4 Subject Vehicle #2

With the EPS torque sensor purposefully miscalibrated, the torque required to maintain straight-ahead travel ranged between 3.5 and 4.5 lb-ft. After the steering mechanism achieved full lock, the EPS reverted to manual mode when a torque value of approximately 7 lb-ft was applied to the steering wheel. The vehicle was controllable when driven, although a constant force was required on the steering wheel to maintain a straight-ahead path. Torque values were measured and noted but were not recorded electronically for Subject Vehicle #2.

6.0 Discussion

A study of 182 female drivers performed in 1973¹ "...tentatively recommends that 15 lbs be the maximum force required to turn a steering wheel at any rate when the power steering system has failed." Since the Malibu steering wheel is 15 inches in diameter (0.625-ft radius), the 15-lb recommended force from the 1973 study would be equivalent to approximately 9.4 lb-ft of torque on the Malibu. The maximum torque recorded during the assisted in-motion portion of the current testing was 4.6 lb-ft (Complaint Vehicle #2, Test 7). The maximum torque recorded during the unassisted in-motion portion of the current testing was 26.3 lb-ft (Complaint Vehicle #1, Test 105). This was significantly more than the maximum steering effort recommended in the 1973 study.

In a test program performed by VRTC in 1985,² six male and four female test subjects were confronted with a sudden and unexpected loss of power steering assistance. During that test program, two of the female subjects stated that they could not turn the steering wheel when confronted with a loss of power steering assistance. The maximum momentary steering effort these two female subjects could produce was approximately 25 lb-ft. Results from the current test program indicate that approximately 26 lb-ft would have been required to steer Complaint Vehicle #1 through a 360° left turn at 8 mph (Test 105) when the EPS was disabled. This may provide some support to VOQs that have been submitted regarding EPS failure on the Malibu that state that the steering "locked up."

In the current test program, the time required for the EPS to return to manual mode (ramp-down time) ranged between 0.4 and 1.6 seconds. Human perception/reaction time for a simple reaction (defined as not having to move hands or feet before reacting) is 0.2 to 0.3 seconds for most people, with drivers over the age of 50 generally requiring somewhat longer.³ The "ramp-down" time that the Malibu EPS provided when a fault was detected was only slightly above the minimum reaction time for most people.

¹ "Human Force Considerations in the Failure of Power Assisted Devices," Man Factors Inc., 4433 Convoy St., San Diego, CA 92111. DOT HS 800-889.

² "Evaluation of Power Steering Assist on 1980-81 General Motors X-Cars," VRTC, ODI 583-8.

³ "The Traffic-Accident Investigation Manual," The Northwestern University Traffic Institute, Ninth Edition, pg 18-6.

7.0 Conclusions

None of the four subject vehicles (including two complaint vehicles) that were tested during this program exhibited a loss of power steering assist unless it was artificially induced. Three of these four subject vehicles were driven at least 100 miles during these tests.

The greatest steering effort encountered during testing with an induced failure of the EPS was approximately 26 lb-ft during a 360° left turn at 8 mph (Complaint Vehicle #1, Test 105). When performed with a functional EPS, this same maneuver required only approximately 4 lb-ft (Complaint Vehicle #1, Test 24). The change in effort occurred virtually instantaneously when the EPS became disabled. Two visual warnings and one audible warning were provided to the driver simultaneously with a loss of power steering assist.

Previous studies suggest that small (5th-percentile) drivers may have difficulty trying to steer the subject vehicle when power assist is lost. Drivers of this stature may describe the steering as "locked" if a loss of power assist was encountered.

Appendix I

List of Instrumentation

Item	Manufacturer	Model	S/N
Speed Readout	Labeco	N/A	
Torque & Position Sensor	Sensor Development	1184	
Digital Volt Meter	Fluke	87III	
Signal Conditioner	Analog Devices	3B18	
Data Acquisition PC	Arts	#1	

Appendix II
Tabulated Test Results from Complaint Vehicle #1

Complaint Vehicle #1 - Functional EPS

Test No.	Max. Torque (lb-ft)	Speed (MPH)	Maneuver
1	System Check		
2	9.8	Stopped	Lock to lock
3	2.1	5	360 deg left turn
4	3.3	5	360 deg rt turn
5	3.4	Stopped	Lock to lock
6	3.2	5-20	S-turn
7	2.0	15	Left turn
8	3.2	8	Full-lock left turn
9	3.2	50-45	Right turn
10	2.5	20	Left turn
11	3.3	15	Right turn
12	3.3	30-15	S-turn
13	3.0	40	Right turn
14	3.0	5	Left turn
15	3.4	5	360 deg rt turn
16	3.7	10-15	S-turn
17	0.9	66	Gradual Lane Change
18	1.4	66	Gradual Lane Change
19	3.3	55-30	Right Turn
20	2.8	20	Left turn
21	1.2	63	Gradual Lane Change
22	3.2	50-45	Right turn
23	2.8	25-10	Left turn
24	3.6	8.5	360 deg Left Turn
25	4.8	6.5	360 deg Rt. Turn
26	3.4	65-45	Right turn
27	2.9	20	Left turn
28	3.0	60-45	Right turn
29	2.7	15	Left turn
30	6.2	7	Full-lock left turn
31	5.4	7	Full-lock right turn
32	2.8	43	Long left turn
33	2.2	40	Long left turn
34	2.6	45	Long left turn
35	3.0	52-43	Long left turn
36	0.9	Stopped	Lock to lock
37	2.6	45	Long left turn
38	2.5	40-50	Long left turn
39	3.5	50-60	Long left turn
40	3.3	45-55	Long left turn
41	9.8	Stopped	Lock to lock
42	3.2	55	Long left turn
43	2.5	62	Obi lane change
44	2.9	60	Long left turn
45	2.8	68	Obi lane change

Test No.	Max. Torque (lb-ft)	Speed (MPH)	Maneuver
46	2.1	82	Straight driving
47	1.6	80	Straight driving
48	3.4	60-50	Rt turn
49	3.0	20	Left turn
50	8.0	Stopped	Lock to lock
51	4.5	0-10	Full lock Left Turn
52	4.4	0-8	Full lock Rt. Turn
53	3.2	50	Long left turn
54	3.3	50	Long left turn
55	3.2	60-0	Lane Change under braking
56	3.1	60-0	Lane Change under braking
57	3.3	60-0-40	Lane Change under braking
58	3.2	0-25	200 ft dia left circle
59	3.1	0-25	200 ft right circle
60	3.4	0-20-0	100 ft. dia left circle
61	3.1	0-20-0	100 ft. dia Rt circle
62	3.3	60-30	Rt Turn
63	3.0	20-0	Lane Change under braking
64	3.1	60-0	Slight S-turn under braking
65	2.8	60-0	Slight S-turn under braking
66	3.1	60-0	Slight S-turn under braking
67	3.2	60-0	Slight S-turn under braking
68	2.8	60-0	Slight S-turn under braking
69	2.8	60-0	Slight S-turn under braking
70	2.8	60-0	Slight S-turn under braking
71	2.8	60-0	Slight S-turn under braking
72	2.9	50-40	Rt turn
73	Data System Error		
74	Data System Error		
75	Data System Error		
76	6.1	10	Full lock Rt. Turn
77	4.3	10	Full lock Left Turn
78	3.1	70-0	S-turn
79	3.1	70-0	Lane Change under braking
80	3.0	65-0	Lane Change under braking
81	2.9	65-0	Lane Change under braking
82	3.4	69-0	Lane Change under braking
83	2.8	69-0	Lane Change under braking
84	3.0	69-0	Lane Change under braking
85	2.7	67-0	Lane Change under braking
86	2.7	74-0	Lane Change under braking
87	3.1	60-30	Right turn
88	3.8	0-12	Full lock Left Turn
89	2.5	0-10	Full lock Rt. Turn

Complaint Vehicle #1 - Non-Functional P/S

Test No.	Max. Torque (lb-ft)	Speed (MPH)	Maneuver
90	26.2	Stopped	Lock to Lock
91	22.8	5	360 deg Left Turn
92	21.3	5	360 deg Right Turn
93	11.2	45	Long Left Turn
94	8.1	45	Long Left Turn
95	7.1	40	Long Left Turn
96	6.5	40	Long Left Turn
97	10.4	60-0	Lane Change while Braking
98	10.0	60-0	Lane Change while Braking
99	15.6	40-0	Lane Change while Braking
100	25.2	40-0	Lane Change while Braking
101	12.2	60-0	Lane Change while Braking
102	11.3	60-0	Lane Change while Braking
103	14.2	40-0	Lane Change while Braking
104	14.3	40-0	Lane Change while Braking
105	28.3	8	360 deg Left Turn
106	24.9	8	360 deg Right Turn
107	10.4	45	Long Left Turn
108	7.4	40	Long Left Turn
109	15.4	60-0	Lane Change while Braking
110	21.2	40-0	Lane Change while Braking
111	17.9	60-0	Lane Change while Braking
112	17.5	40-0	Lane Change while Braking
113	17.5	60-0	Lane Change while Braking
114	17.6	40-0	Lane Change while Braking
115	17.6	60-0	Lane Change while Braking
116	18.0	40-0	Lane Change while Braking
117	19.9	25	200 ft Radius left circle
118	23.3	20	100 ft Radius left circle
119	20.7	25	200 ft Radius right circle
120	23	20	100 ft Radius right circle
121	23.6	10	50 ft Radius left circle
122	25.2	10	50 ft Radius right circle
123	13.5	70-0	Lane Change while Braking
124	10.4	70-0	Lane Change while Braking
125	11.8	70-0	Lane Change while Braking
126	10.5	70-0	Lane Change while Braking
127	13.4	55-10	Long Right turn
128	16.7	15	Left Intersection Turn
129	23.4	10	360 deg Left Turn
130	24.6	10	360 deg Right Turn
131	37.5	Stopped	Turn Wheel to Left, max. capability of driver
132	37.5	Stopped	Turn Wheel to Right, max. capability of driver

Appendix III
Tabulated Test Results from Complaint Vehicle #2

Complaint Vehicle #2 - Functional EPS

Test No.	Max. Torque (lb-ft)	Speed (MPH)	Maneuver
1	2.9	10	360 deg Left turn
2	3.5	10	360 deg Rt turn
3	3.4	25	LH 200 ft. Radius turn
4	3.1	20	LH 100 ft. Radius turn
5	3.0	14	LH 50 ft. Radius turn
6	4.3	25	RH 200 ft. Radius turn
7	4.6	19	RH 100 ft. Radius turn
8	3.4	13	RH 50 ft. Radius turn
9	4.1	32	Winding Road Course SB
10	3.8	35	Winding Road Course NB
11	3.1	30	Multiple lane changes
12	3.3	30	Multiple lane changes
13	3.2	55-0	Lane Change while braking
14	3.3	60-0	Lane Change while braking
15	4.1	40-0	Lane Change while braking
16	3.2	40-0	Lane Change while braking
17	3.9	10	360 deg Left turn
18	3.4	10	360 deg Rt turn

Appendix IV
Tabulated Test Results from Subject Vehicle #1

Subject Vehicle #1 - Switchable EPS

Test No.	Max. Torque (lb-ft)	Speed (mph)	Ramp Time (sec.)	Max. Torque w/ Assist	Maneuver
1	3.2	10	N/A	13.2	Rapid S-Turn with assist
2	2.4	61	N/A	2.4	Rapid S-Turn with assist
3	3.3	27	N/A	3.3	Rapid S-Turn with assist
4	3.5	27	N/A	3.5	Rapid S-Turn with assist
5	27.2	Stopped	N/A	N/A	L/R 100 deg. w/o assist
6	System check		N/A	N/A	
7	2.6	6	N/A	2.6	180 deg. Left turn with assist
8	14.1	6	1.5	2.6	180 deg. Left turn with disconnect
9	3.7	20-10	N/A	3.7	Long Left Turn with assist
10	20.7	20	0.4	2.7	S-Turn with disconnect
11	16.8	20	1.4	5.8	S-Turn with disconnect
12	20.3	25	1.2	2.4	Right Turn with disconnect
13	22.6	20	1.6	2.7	Left Turn with disconnect
14	21.0	30	1.3	3.2	S-Turn with disconnect
15	18.9	25	1.0	2.8	S-Turn with disconnect