ENGINEERING ANALYSIS CLOSING REPORT
EA04-012

SUBJECT: Hydraulic Pump Shaft Failures

VEHICLES: 2000 - 2004 Chevrolet and GMC C/K/G 2500 and 3500 series vehicles equipped with a Hydro-Boost system

ALLEGED DEFECT: The hydraulic pump shaft can shear, resulting in a deterioration of brake effectiveness, extended stopping distances, and complete loss of power steering assist.

CORRESPONDENCE:

25 May 04	NHTSA EA Information Request (IR) to Delphi
16 July 04	Delphi Response to EA IR letter
07 June 04	NHTSA EA Information Request letter to GM
26 July 04	GM Response to EA IR letter
06 Jan 05	573 letter from GM

POPULATION:

Make	Model	2000	2001	2002	2003	2004**	Total
Chevrolet	Avalanche	0	0	6,087	2,104	1,461	9,652
	Silverado/Fleetside	193,386	186,959	206,086	219,081	234,154	1,039,666
	Suburban	7,918	17,199	7,881	8,233	7,401	48,632
	Express	82,489*	74,168*	75,321*	60,081	57,639	349,698*
GMC	Sierra	62,608	57,292	62,775	64,972	71,559	319,206
	Yukon XL	2,604	5,518	2,590	3,013	2,390	16,115
	Savana	31,968*	28,523*	26,381*	23,307	31,288	141,467*
Total		380,973*	369,659*	387,121*	380,791	405,892	1,924,436*

* A total of 43,947 vehicles without Hydro-Boost systems were removed from these populations. The total adjusted population is 1,880,489.

** Vehicle production as of June 10, 2004.

BASIS: This engineering analysis was opened based on complaint and warranty data obtained during the Preliminary Evaluation, PE04-004. ODI upgraded the investigation to perform a full technical analysis of the issue and conduct testing.

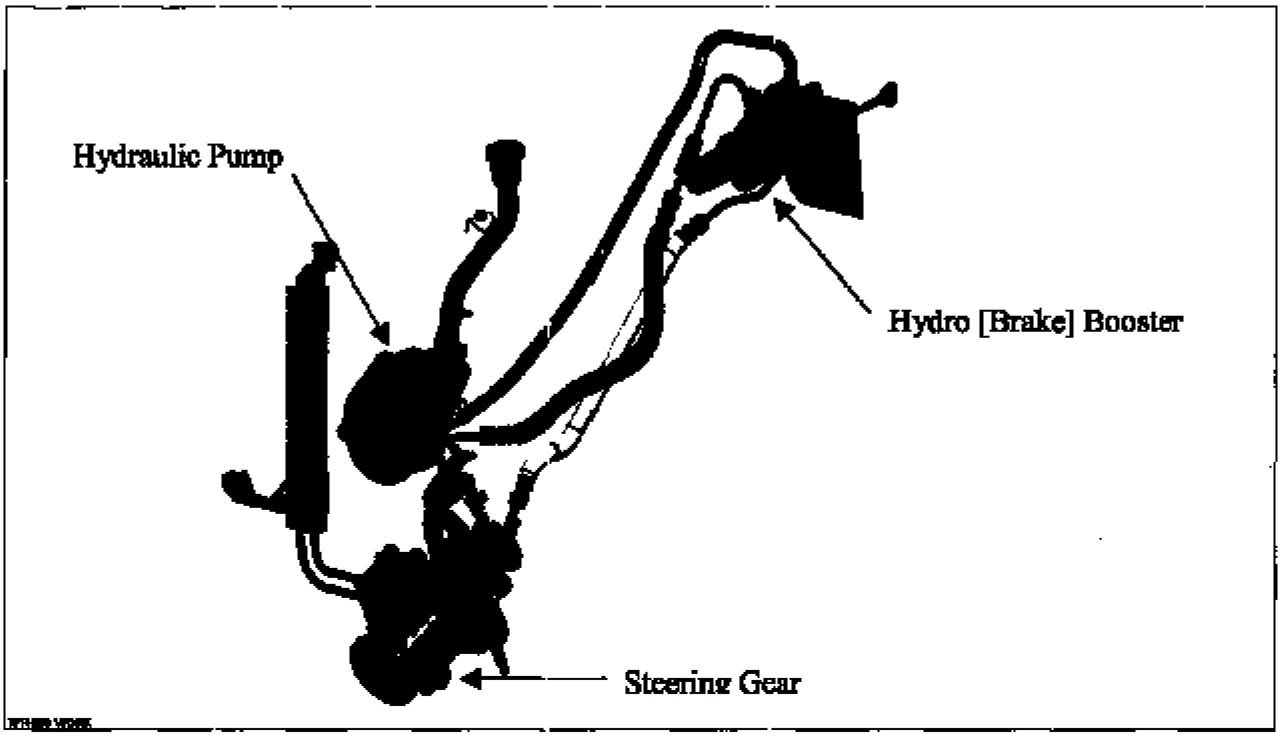
COMPLAINT & CRASH STATUS:

EA	Open			Closed		
	ODI	GM	Total	ODI	GM	Total
Complaints	30	261	291	34	291	325
Crashes	3	20	23	4	24	28
Injuries	1	3	4	1	5	5

The EA expanded the PE population to include all Model Year (MY) 2003 and 2004 subject vehicles. Doing so did not significantly increase the number of complaints, crashes, or injuries. GM identified three distinct populations within the subject vehicle population. These will be discussed in greater detail. All duplicates in this table have been eliminated.

DESCRIPTION OF COMPONENT/VEHICLE SYSTEM: The subject component is the hydraulic pump used in the Hydro-Boost system. The Hydro-Boost system links the power brake and power steering systems together by a common hydraulic pump. Figure 1, below, illustrates the three primary components of this system, the hydraulic pump, brake booster, and steering gear.

Figure 1: Hydro-Boost System



The steering shaft assembly transmits driver input from the steering wheel to the steering gears. Power steering fluid flows through the system from the hydraulic pump to the Hydro-Booster. Three hydraulic lines connect the booster to the steering system at the booster's pressure, gear, and return ports. The hydraulic pump is a common power source for the hydraulic brake booster and the power steering gear. The power steering fluid not only assists the steering gear, but also provides the brake booster with hydraulic fluid to assist during the normal manual pedal brake application. The magnitude of flow and pressure from the pump required to provide power assist to both the steering gear and the brakes varies. The size of the steering gears and brake Hydro-Booster vary based upon the size of the vehicle. The pump flow and pressure specifications were established through the performance criteria, analysis and development testing of the various power assisted steering and brake components installed in the vehicle. Typically, the hydraulic pump supplies two to four gallons per minute and has a 1,000 to 1,500 psi relief pressure.

The brake booster is a hydro-mechanical device consisting of a spool control valve, a mechanical ratio charging mechanism, a power piston, and a pneumatic accumulator reserve system. Normally mounted in the engine compartment on the firewall, the booster is actuated by the brake pedal inside the vehicle. Fluid flow from the pump enters the booster through the pressure port, flows around the open center spool valve, and exits the booster from the gear port. Fluid from the gear port flows to and through the power steering gear returning to the pump reservoir. The return port is necessary to allow a small amount of internal leakage to lubricate the pump and to allow booster release flow to return to the reservoir. The booster's primary valve was designed in such a manner that the steering and braking systems do not noticeably interact.

The Hydro-Boost unit includes a pneumatic accumulator, which provides a transition between power assisted braking and manual braking in the event of pressure supply loss and serves as a reserve system. The number of accumulator-assisted stops varies depending on previous inputs from the steering and braking maneuvers. The accumulator stores the maximum pressure previously demanded. Once that reserve is tapped into, the available reserve is diminished until the system is stressed to a higher level than what is stored in the accumulator. This requires the driver to revert to manual braking with less warning.

WARRANTY: During the PE GM reported 20,404 warranty claims on the model year 2000 through 2002 population, a rate of 1.8%. The subject population was expanded to include MY 2003 and 2004 when the investigation was upgraded to an EA, an increase of 786,683 vehicles. Also at that time, the subject vehicle was redefined as only those having the Hydro-Boost system, resulting in the removal of 43,947 G vans. GM's EA response, which covered updated information on MY 2000-2002 vehicles as well as MY 2003-2004 vehicles, reported an increase of 2,348 warranty claims for a total of 22,752 on an adjusted population of 1,880,489 (MY2000-2004). Of the 2,348 new claims, 975 were on Model Year 2003-4 vehicles, a rate of .12%. The data indicated that the failure rate was much higher for the earlier vehicles.

The warranty data showed distinct subpopulations based on build date, that roughly coincided with manufacturing changes. These changes include the supplier's discontinued use of reground rotors and the implementation of new ring and rotor clearances along with new manufacturing limits. Earlier vehicles did not incorporate these changes. As a result, the earliest production for MY 2000 vehicles exhibited the highest failure rates.

VRTC/ODI TESTING: To assess the steering and braking performance degradation that occurs when a pump shaft fails and to understand how drivers respond to the loss of brake and steering assist, the Vehicle Research and Test Center (VRTC) conducted testing using a 2001 Chevy Silverado K3500 dual rear wheel pickup. The test vehicle had a Gross Vehicle Weight Rating (GVWR) of 11,400 pounds and a 15-inch diameter steering wheel. Full details of all testing are available in the VRTC test report.

The vehicle was initially tested to a United Nations steering standard to help assess the amount of effort needed to steer the vehicle without power steering.[1] The test vehicle was tested on 12 meter and 20 meter radius turns with an intact and failed power-assist unit. Each test was completed in four seconds with a maximum effort of 250 in-lb and 500 in-lb for an intact and failed system, respectively. The test vehicle required 45 in-lb for the intact system and 300 in-lb for the failed system. While the test vehicle passed both tests, there was a nearly seven-fold increase in the required effort to complete the turn on a larger radius course. For comparison purposes, the test was also run with a failed unit on the smaller radius course to illustrate the effect a failed system would have on driver steering efforts. Testing on the smaller course yielded a measurement of 416 in-lb, which is over a nine-fold increase in steering effort when compared to a system with an operational Hydro-Boost system.

VRTC also conducted a series of constant deceleration stops using gradually increasing pedal forces to correlate brake line pressure with deceleration. Full results are included in the VRTC test report.

VRTC testing revealed that pressure for back-up power-assist is stored in the hydraulic accumulator on Hydro-Boost units. The accumulator is charged by pressure from the hydraulic pump. The pump does not build pressure unless there is a steering motion or a brake application. Pressure in the accumulator would appear to be only as much as the highest pressure developed by the pump.

To measure pump pressure during testing, VRTC installed a pressure gauge on the supply line from the pump to the Hydro-Boost unit. The hydraulic pump generated about 500 psig when the driver stepped on the brake to shift out of Neutral. Low speed steering maneuvers generated 500 to 1,000 psig.

The results show that the loss of boost, when coupled with a depleted reserve, sharply increases brake pedal effort. Drivers who become accustomed to applying 20 lbs for a moderate 0.3 g deceleration, may not realize that they have to apply 130 lbs or more if they lose power-assist. Under these conditions, many drivers perceive that they have no brakes and fail to press hard enough. In contrast, during an FMVSS 105 failed-booster stop, the driver immediately applies and maintains a force of 150 lbs to stop the vehicle within the required distance.

A typical vacuum booster would be at mechanical push-through at around 40 lbs pedal force. The hydro-boost unit does not drop off, due to mechanical push-through, until above 70 lbs. The hydro-boost probably would have gone higher but the brake pedal was against the floor between 70 and 80 lbs and the highest BLP possible was 1,620 psig. This pressure was more than enough to achieve the maximum deceleration available from the tires. The gain with normal power-assist is about 0.016 g per pound, which is within the recommended limits for effective vehicle control.[2]

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[1] *Uniform Provisions Concerning the Approval of Vehicles with Regard to Steering Equipment*, Addendum 78, Regulation No. 79.

[2] "Brake Force Requirement Study: Driver-Vehicle Braking Performance as a Function of Brake System Design Variables", April 1970, R.G. Mortimer, L. Segal, H. Dugoff, J.D. Campbell, D.M Jorgeson, R.W. Murphy, Highway Safety Research Institute, University of Michigan.

During this investigation, VRTC also conducted a human factors study, recruiting twenty-one drivers from TRC's (Transportation Research Center) staff – twelve males and nine females. Each driver completed four tests. The first test gauged an unsuspecting driver's reaction to the simultaneous failures of the brake booster and power steering systems. The second test (a static test) determined each driver's maximum steering effort. The third test assessed a driver's ability to control the vehicle knowing that a failure could happen. The final test gauged the driver's ability to control the vehicle while knowing that the power steering pump had failed.

The tests revealed driver difficulties in controlling the vehicle when the pump fails. On average, males were able to exert more torque than females. In general, drivers of both genders were unable to negotiate the turns laid out in the tests.

SERVICE BULLETINS: Although GM did not issue any applicable service bulletins, it prepared two Preliminary Information (PI) documents concerning unsatisfactory performance of the hydraulic pump in MY_2003 and 2004 vehicles. Unlike a service bulletin, the information contained in a PI is available only when a GM dealer or representative enters a VIN into the Technical Assistance Center (TAC) system to access these documents. In contrast, service bulletins are supplied to all GM dealers and representative and routinely reviewed by service technicians.

PI01863[3] instructed technicians to diagnose the vehicle using the Power Steering Test Procedures if an owner complained about difficulty steering during "parking lot type maneuvers." If the vehicle passed this test, no work was required, as GM viewed this as a normal phenomenon.

On March 23, 2004, GM published PI01897.[4] PI01897 contained instructions similar to the prior PI, but added that if the customer's situation warranted, a replacement pressure control valve (PN: 26095470) was available to provide additional steering assist.

MANUFACTURE, DESIGN, MATERIAL COMPOSITION MODIFICATIONS: Delphi, the hydraulic pump manufacturer, conducted four manufacturing changes during the subject vehicles' production. After these changes were made, GM asked Delphi to make an additional change. These changes are noted below:

- October 1, 1999: Delphi Plant 3 completely stopped all rotor salvage regrinding;
- November 1, 1999: Delphi Plant 3 retargeted the pump ring/rotor clearance by 0.00005" and changed the housing surface flatness manufacturing limits from 0.0001" convex/0.0005" concave to 0.0001" convex/0.0006" concave;

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[3] Lack of Steering Assist When Stopped or During Parking Lot Type Maneuvers – kw brake power assist oil no hard noise booster hydraulic slow low speed bind weak #PI 01863 – (03/11/2004).

[4] Lack of Steering Assist or Shudder During Parking Lot Maneuvers – kw brake power oil hard noise booster hydraulic slow low speed bind trailer weak #PI01897 – (03/23/2004).

- February 15, 2000: Redundant Marposs gauging was added to measure rotor thickness;
- May 15, 2001: Rotor surfaces taper controlled thru monitoring; and
- February 2, 2004: Post-pressure plate design pumps went into vehicle production.

<u>GM'S AND DELPHI'S EVALUATION OF THE ALLEGED DEFECT</u>: GM's February 23, 2004 response to ODI's information request contends that drivers can still stop and steer vehicles with a failed Hydro-Boost system. GM believes that the pneumatic accumulator provides a transition between power-assisted braking and manual braking in the event of a pump failure. Once the accumulator is depleted, GM states that "the brake system operates in the manual mode," which requires the driver to exert increased brake pedal force to stop the vehicle within the desired stopping distance. As a result, GM does not view the failure of the Hydro-Boost system as an unreasonable risk to motor vehicle safety. GM adds that even with a depleted reserve, "[t]he subject vehicles comply with the no-power brake assist condition stopping distance requirements identified in [FMVSS 105]."

With respect to the power steering system, GM notes that once the power assist disappears, the steering system reverts to manual steering. According to GM, the system is designed to enable the driver to control the vehicle with low or no hydraulic fluid in the system. Because power steering effects are greatest at the lowest speeds, the loss of power steering is unlikely to be associated with serious injuries.

GM's response identifies several factors that may contribute to hydraulic pump shaft failures, including: pressure plate deflection/pump seizure; pressure plate flatness; improper ring/rotor clearance; and use of an oversized/tapered rotor.

Delphi explains that the subject pumps were designed over 40 years ago and have undergone continuous improvements, including the capacity to sustain increased pressure. The supplier echoes GM's position that in the event of pump failure, vehicle steering and braking can still be controlled and that the greatest impact on control is primarily during low speeds.

<u>OBSERVATIONS</u>: The halting of rotor regrinding operations improved the hydraulic pump's performance. Delphi's changes to the pump ring/rotor clearance and housing surface flatness manufacturing limits also had positive effects on pump performance. Manufacturing changes implemented on February 15, 2000 and May 15, 2001 improved Delphi's ability to detect and remove non-compliant products before reaching GM. Both of these changes had minor impacts on the subject vehicle failure rate. The last product change, requested by GM, was incorporated into vehicle production on February 2, 2004. The pressure plate within the hydraulic pump was significantly redesigned to provide better pump performance during high demand maneuvers, such as parking. The "post pressure plate design," was tested and found to be capable to endure the full test protocol, where the original design seized on the first of 34 cycles. These pumps are now available as service replacements, are compatible with previous applications and have superseded the production of previous pumps.

CONCLUSIONS:

1) Failure rates of brake or steering power-assist are typically very low;

2) Loss of power-assist on steering or brakes can create a hazardous situation if the failure occurs at exactly the wrong moment under the wrong conditions;

3) A high failure rate places the public at an increased risk; and

4) A combined loss of assist (power steering an power braking) increases the risk as drivers must process additional inputs and make more decisions.

On January 6, 2005, GM submitted a field action program (copy attached). Under this program, 98,221 MY 2000 vehicles built from May 1, 1999 to October 14, 1999 will be recalled (NHTSA Recall No. 05V-005) and have the latest version of the pump installed. GM and ODI agreed upon this subset population based on the available complaint, crash, and warranty data analyses, and the accompanying manufacturing improvements that have taken place. These recalled vehicles have exhibited high warranty rates and consist of all vehicles equipped with pumps built with reground salvaged rotors.

The closing of this investigation does not constitute a finding by NHTSA that no safety-related defect exists on the remaining population. ODI will continue to monitor the remaining population and reserves the right to take further action if warranted by the circumstances.

Safety Defects Engineer — 2/28/05 Date

I Concur:

Chief, Medium & Heavy Duty Truck Division — 2/28/05 Date

Director, Office Of Defects Investigation — 2/28/05 Date