

Artificial Steering Feel

Daniel E. Williams and Kenneth A. Sherwin
TRW Commercial Steering Systems

Copyright © 2009 SAE International

ABSTRACT

A computer controlled steering system providing an artificial feel or synthetic torque feedback to the driver has recently been launched into production in the commercial vehicle market. This work compares the artificial feel control strategy with prior electric power steering control strategies and hydraulic power steering. Suitability for integration with other vehicle control systems such as lane sensing and electronic stability enhancement is explored.

BACKGROUND

An advanced steering system that provides a computer-generated synthetic torque feedback to the driver has been available in select heavy vehicles for the past two years. For duty cycles typical of a pick-up and delivery vehicle, distinguished by relatively low vehicle speed and large displacement steering inputs, driver workload is reduced by approximately 75%.ⁱ Over-the-road commercial vehicles have a somewhat contrasting duty cycle dominated by high speed lane maintenance. For these vehicles the synthetic torque increases apparent precision to the driver. The combination of unprecedented speed-proportionality and on-center precision allow this system to add significant value to commercial vehicles by enhancing steering system performance.ⁱⁱ

Commercial vehicle duty cycles are characterized by low lateral accelerations. In general, the lateral accelerations of commercial vehicles are limited by rollover. Passenger cars do not have this limit, and therefore can generate lateral acceleration until the

contact patch of the tires can no longer produce additional lateral forces resulting in increased yawing moments. Regardless of the different duty cycles, the advantages of artificial steering feel in passenger car application are likely to include enhanced ability to interface with other vehicle control systems, e.g. electronic stability enhancement and lane keeping. Enabled by a new control strategy, more precise transmission of haptic signals to the driver is possible than with conventional electric power steering (EPS) control strategies.

Conventional hydro-mechanical power steering systems generate an auxiliary assist based on input torque from the driver through the handwheel. This input torque deflects a torsion bar that in turn results in the displacement of a rotary valve. The amount of hydraulic pressure used to generate the steering assist is determined by valve displacement, and is therefore ultimately a function of input torque. Therefore actuator

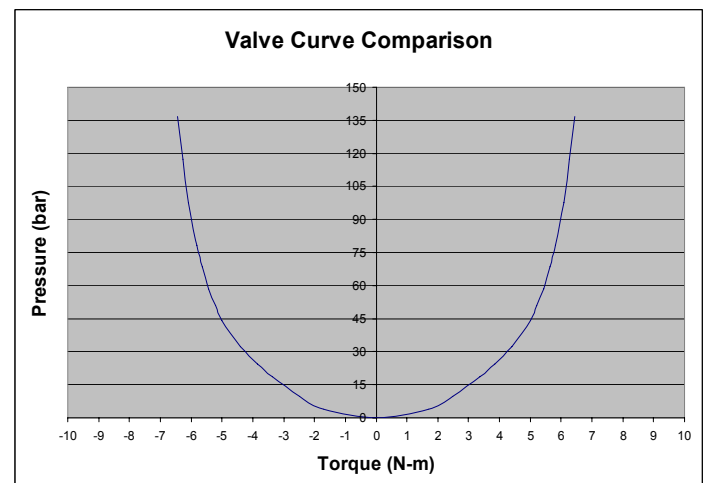


Figure 1: Typical Hydraulic Valve Assist Curve

effort is a function – specifically a nonlinear amplifier - of input effort commonly referred to as the “bath-tub” curve shown in Figure 1. The “bath-tub” curve is a natural consequence of hydraulic flow through the open center control valve used in the steering gear. For many years it has worked well in power steering applications, producing minimal assist on center, and higher assist levels away from center to minimize the peak parking efforts required from the driver. Such an actuator can be referred to as “open loop” in the frequency range of driver input as actuator output torque is a function of input torque. (Although in a strict control systems sense it is a closed loop position follower with attendant high frequency potential instabilities).

For some time an electrically actuated passenger car steering system has been used to directly replace the hydraulic system in some smaller passenger cars. Electrical power steering includes an integrated assembly consisting of an electric motor, ECU, position and torque sensors requiring an input connection including only power and CAN. The upper end of the unit is connected to the handwheel, and the lower end to the pinion and mechanical rack. With the advent of electrical power steering, it is much easier to tune a passenger car steering system to specific vehicle operating conditions, such as speed, while intentionally reproducing the nonlinear behavior presently produced by open-center hydraulics of little assistance near center, and disproportionately large assistance away from center. The on-demand nature of EPS eliminates the parasitic losses associated with open-center hydraulic power steering. Electric power steering also provides packaging and environmental benefits relative to the hydraulic system it replaces.^{iii, iv}

The commercial vehicle application of EPS hardware, shown in Figure 2, is different than the passenger car

application. The hydraulic gearbox is retained rather than replaced as in the passenger car application. This hardware configuration can be generically referred to as torque-overlay. The high torques and forces required to steer heavy axles make the power density of hydraulics an attractive actuation technology for commercial vehicles. The conventional steering system has proven to be effective, inexpensive, durable and reliable, however it loses many of these advantages when programmability is incorporated into the hydraulics. Using the control strategy described below, the electric motor is used to modify torque feedback to the driver, and the hydraulic gearbox does the work required to steer the heavy axle. Thus driver feedback and actuation are decoupled. Because torque feedback to the driver is synthetically derived independent of road wheel forces, the proposed strategy is easily portable across vehicle types.

In many respects performance characteristics of steering systems have been compromised or constrained by steering system feel. The fundamental compromise in steering system design is that drivers favor a relatively high stiffness around the center position when they are maintaining a lane, and also prefer low efforts when they are parking a vehicle. This is particularly true of commercial vehicles, where high power is required to statically steer heavy axles.^v The “bath-tub” curve inherently provides little assistance on center, so that steering feel perceived by the driver is partially determined by mechanical steering and vehicle properties generated at the contact patch and propagated up the mechanical drive train. At higher input torque values increased assistance overwhelms the mechanical effects, and the driver perception is determined by the hydraulic valve and torsion bar.

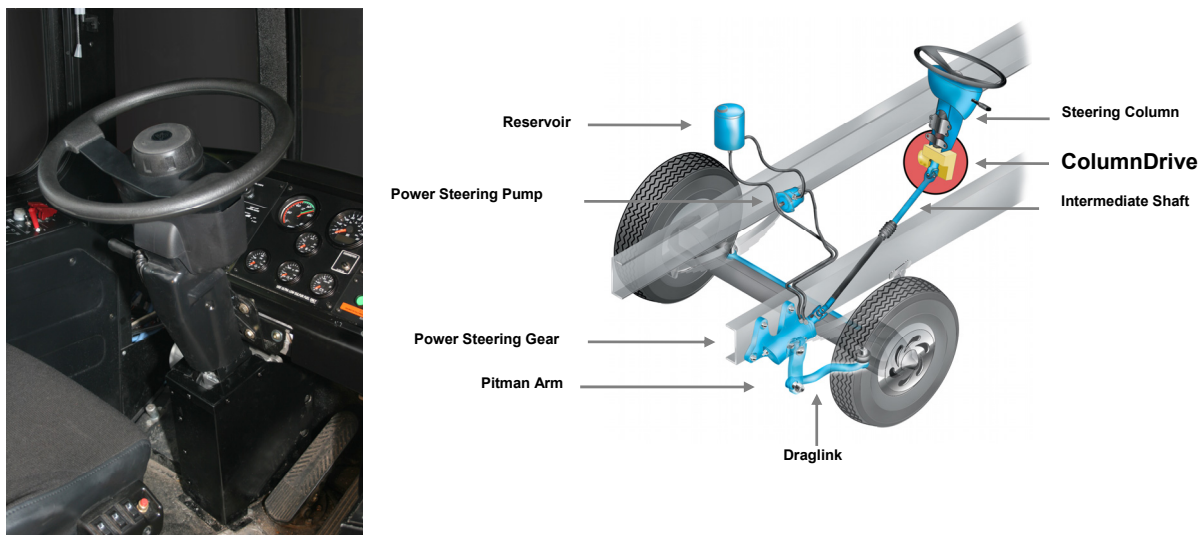


Figure 2: Pictorial and Schematic Commercial Vehicle ColumnDrive Installations

Lash or looseness is particularly objectionable to the driver on center while maintaining a lane. If lash is present in the steering system on center, the driver will constantly be uncertain about how much input is required to correct the vehicle position within the lane. Lash is an inevitable effect of wear in interfacing mechanical parts and can sometimes be improved by designing these parts with a bit of preload. This preload causes unavoidable friction, which is as offensive as lash. In both cases, the unique relationship between handwheel torque and handwheel position is sacrificed as there can be a range of handwheel torques for a given displacement, or vice versa. Worse yet, in many cases different parts of the mechanical connection between the handwheel and road wheel contribute lash and friction respectively, resulting in complex nonlinear behavior. Given sufficient on-center stiffness, this

uncertainty or unpredictability in the heavy vehicle steering system is most objectionable.

Much of the theoretical understanding of the driver comes from the aerospace industry's attempt to model pilot behavior. The torque exerted by the driver on the handwheel is reacted against by the steering system dynamics, with the net sum of torques producing a handwheel motion. This handwheel motion is sensed by the hands and arms of the driver and proprioceptively fed back to the driver's brain where it is compared with the intended handwheel displacement.^{vi,vii} Thus the uncorrelated handwheel torque and position are ultimately reconciled through driver control effort. To the extent that torque and position are well correlated, this control task is less intense.

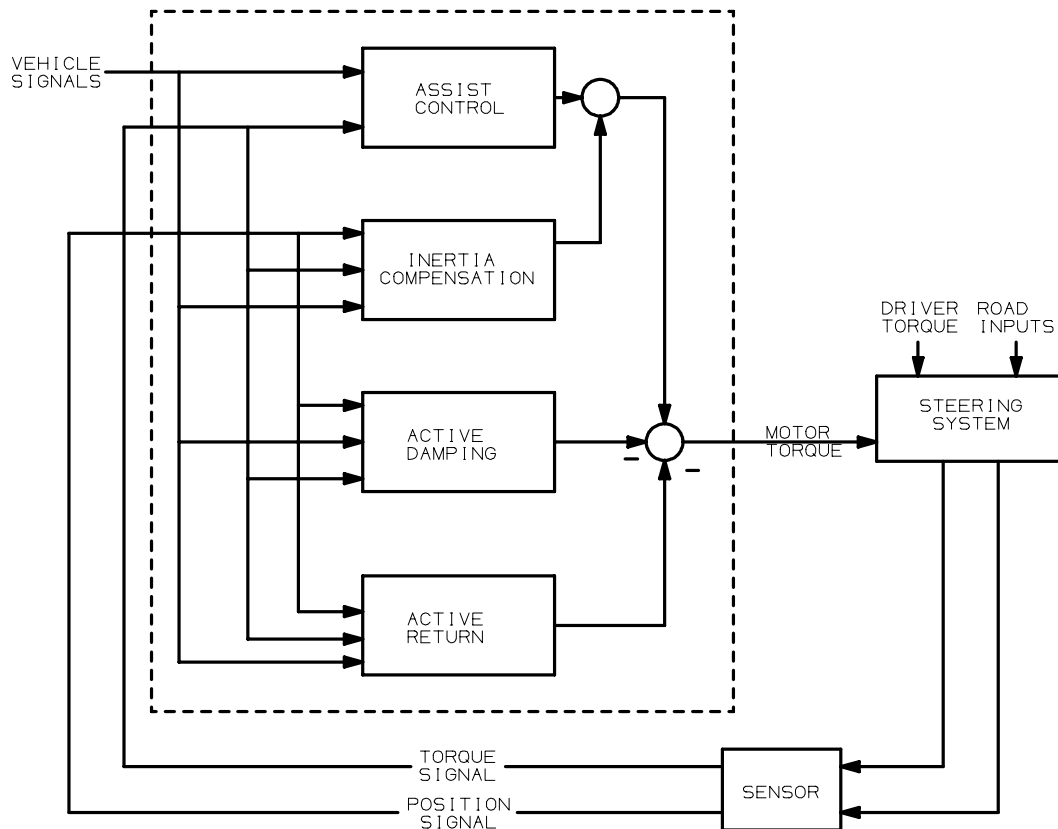


Figure 3: Typical EPS Passenger Car Torque Control [iv, viii]