# Steering in the Right Direction

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Electric power steering provides fuel savings and more.

There are several motor control approaches to electrically assist or directly control power steering. Systems such as electric power-assisted steering (EPAS) or electric hydraulic power steering (EHPS) work with the vehicle's hydraulic systems. Newer electric or electronic power steering (EPS) systems eliminate the hydraulic portion. Initially developed for their fuel-saving potential, either EPAS or EPS systems are required instead of belt-driven hydraulic power steering (HPS) systems on hybrid vehicles where the engine is off at idle. In addition, EPS is an integral part of advanced stability control systems. This report addresses the control, sensing and power aspects of these rapidly increasing systems and the changes that are occurring in this critical safety system.

## EPS SYSTEMS

According to a Frost & Sullivan report (http://transportation.frost.com), research analyst Jatin Khanna expects EPS systems to almost completely overtake HPS systems by 2020 in Japan. In Europe, where fuel economy is also important to drivers, the acceptance and adoption rate of EPS and EPAS is also quite high with some estimates showing as high as 50% of new vehicles equipped with these systems. TRW projects that by 2010, 50% of cars produced worldwide will incorporate some form of electrically assisted steering system. The accuracy of these projections depends on the added functionality that EPS provides to drivers.

For example, rear-mounted engines need EPS or EHPS. Up until 2005, Toyota's MR2 had EHPS according to David Lee, senior product education development administrator for the University of Toyota. Boost was controlled by the electric motor because the MR2 was a rear-wheel drive, rear-engine vehicle. The EHPS allowed an easy mounting in the front of the vehicle and the traditional pump was driven by a motor instead of the accessory belt.

The Frost & Sullivan report stated that EPS meets the value proposition for increased acceptance compared to the EPAS and HPS. EPS provides fuel savings as high as 0.2 to 0.3 liters per 100 kilometers compared to HPS systems and EPS has a higher capability for integration. Figure 1 shows different approaches for EPS system architectures.

Today, Toyota only offers EPS and not EHPS for the U.S. market. “Right now we have two regular internal combustion cars that have electric power steering: our little subcompact Yaris and the current generation that was launched last year of the RAV-4,” said Lee. Both of these are 12 V systems with similar structure.

The system consists of a steering-assist motor on the column with a steering rack at the wheels and a torque-sensing device in the steering column. The column is split into two pieces: the part attached to the steering wheel connects to the lower portion with the steering rack through a torsion rod with a torque- sensing device. “The upper half and lower half have magnetic sensors and as the upper half of the steering column starts to move, the magnetic sensors send a signal to the power steering control computer,” said Lee. The computer moves the motor to match the input torque command. The quicker the driver turns the wheel, the quicker it will respond, with response time in the milliseconds. This system eliminates the lag and the cavitation that can occur in hydraulic systems.

Unlike hydraulic systems that react only to engine speed, the electric system allows calibration for greater motor boost at low speeds where it is required and less at high speed when it is not needed. The driver gets a better road feel at higher speeds, and the boost required in parking situations, where it is more difficult to turn the wheel.

## CONTROL ASPECTS

Motor control for EPS comes from microcontrollers (MCUs) or digital signal processors (DSPs). “We have the DSC family and some eSys type families going into these applications,” said Jim Shockey, a marketing manager in the Freescale Semiconductor Transportation and Standard Products Group (TSPG). The eSys MCU is a powertrain part from the lower end of Freescale's high-performance 32-bit PowerPC family. The DSC will be in EPS systems within the next couple of years, probably 2008. Today, these applications use high-speed CAN for communication. When steer-by-wire is implemented, a FlexRay protocol may be used for communication.

There are lots of discussions going on regarding safety and how the industry needs to move forward with these applications. One of the key international bodies that is trying to answer the questions in this area is the International Electrotechnical Commission (IEC) with the IEC 61508 standard that addresses the functional safety of electrical/electronic/ programmable electronic (E/E/PE) safety-related systems. This broad set of criteria generally targets safety requirements.

“Some of our customers are looking at how they can apply those standards toward electronic power steering,” said Shockey. While the IEC standard does not explicitly state the requirements for features or capabilities, it does establish criteria for system designers. Today, meeting the criteria could mean using two CPUs for redundancy in a safety system. One CPU performs the activity and the other monitors the first's behavior as a watchdog.

“The goal as they move forward is to ensure the electronic power systems have at least a fail silent type behavior,” said Shockey. Companies designing EPS systems are using the IEC spec to make decisions for future systems. Determining the extent of redundant control is what suppliers are grappling with. Freescale uses error correction coding (ECC) that can detect faults on the chip and in the memory — a fairly large portion of the chip. They can assure functions of portions of the chip, but assuring behavior of the processor has other challenges. Different companies are looking at different approaches.

Shockey believes that when this is sorted out it will change the way future EPS systems are designed. Today, it is being solved with more complex systems with more components. For the most cost-optimized systems, system designers need to split the functionality so they have minimum components and reliable operation. Figure 2 shows the typical components used in an EPAS or EPS system.

## SENSING OPTIONS

The sensors shown in Figure 2 have critical specifications that have motivated several sensor designs using different technologies according to Mark White, FAE manager from Melexis. For the steering wheel position and speed sensor, critical parameters include:

- angular range: ±900° (±2½ turns);
- angular resolution: 0.1° (also ESP driven);
- angular accuracy: ± 1 to ± 2°;
- absolute — true power on;
- response time: < 10 ms;
- dynamic range: up to 2000°/s; and
- standby current: < 100 µA (ideally zero).

Sensor technologies used in this application include linear Hall Effect, Triaxis Hall, magneto-resistive (AMR or GMR), inductive and optical.

For steering torque, the critical parameters are:

- torque range: ± 10 N-m;
- accuracy:
  < 1% full scale around "zero-torque"
  < 3% to 5% full scale elsewhere; and
- response time: < 500 µs

Sensor technologies for steering torque depend on whether the design is compliant or non-compliant. For a compliant approach with micro-angular displacement (±3°) using a torsion bar along the steering shaft, sensing technologies include the same choices as the steering wheel position and speed sensors. For non-compliant, true direct torque measurement on the column, sensing technologies include: flux gate (with magneto-strictive material) and surface acoustic wave (SAW).

A final sensing requirement in EPS is for motor position and speed in the brushless dc (BLDC) commutation. Critical parameters in this application are:

- rotation speed: up to 15000 rpm;
- angular resolution: < 0.1°;
- angular accuracy: ±1°;
- speed resolution: <2 rpm;
- speed accuracy: ±5 rpm; and
- response time: <100 µs.

Sensing technologies for the BLDC include: resolver (plus a resolver-to-digital converter), Triaxis Hall (plus a DSP), and magneto-resistive (plus a DSP). Some of the newest sensor designs for EPS applications involve the use of advanced inductive techniques and Melexis Triaxis Hall Effect sensor.

## POWER CONSIDERATIONS

The amount of electrical power required for EPS has limited the system's usage primarily to smaller vehicles. Part of the issue with a 12 V system is getting enough instantaneous power to have a full electric power steering for a large car. "As of today, I think you'll find them on smaller cars and not so much on large ones," said Phil Headley, chief enginee, Advanced Technology, Continental Automotive Systems.

TRW's electrically assisted steering (EAS) specifically targets the small car segment. The integrated EPS system is a column unit that uses a low inertia permanent magnet ac motor. A worm gear transmits the assist torque from the motor to the steering column. The system provides a maximum assist torque of 70 Nm (rack assist force 8500 N) with peak output power of 470 W. This requires peak battery current of 70 A at

13.5 V. EPS systems can easily exceed 100 A using a standard 12 V battery supply.

Hybrids and electric vehicles change the rules for EPS. These vehicles have higher voltages available and they require an electric source to drive the pump since the engine is stopped at idle to conserve fuel. Both EPAS and EPS are currently used on hybrid vehicles.

Toyota's Prius has a high-voltage EPS system that operates around 40 V but it is similar to the 12 V system. It is Toyota's oldest EPS system and the first EPS system the company offered in the United States. The system provides power steering when the engine is off. In vehicles with small engines such as the Prius and Yaris that have 1.5 liter engines, the losses of a hydraulic or EHPS system that continuously run the pump would be quite significant.

One of the largest vehicles using EPS today is Toyota's Highlander. The system uses a steering rack to handle heavier front axle loads. The Highlander and the Camry hybrids have a system that works on the same principles as the Prius with a torque sensor in the steering column, but the assist motor's location changes from the steering column to into the steering rack. As shown in Figure 3, the higher-performance motor runs on 42 V in the Highlander with a buck dc-dc converter reducing the vehicle's 288 V battery voltage to 42 V. The Camry runs between 27 V and 34 V.

EPS is only offered on the hybrid versions of the Camry and Highlander. The availability of EPS allows it to play a critical role in Toyota's vehicle dynamics integrated management (VDIM) system. However, electrically assisted steering has also added a new dimension to electronic stability controls.

## EPS IN VEHICLE DYNAMICS/ELECTRONIC STABILITY CONTROLS

Continental's electronic steer-assisted steering (ESAS), shown in Figure 4, provides an offset to normal hydraulic steering through a cluster gear arrangement. For advanced electronic stability control, electric steering adds another control aspect.

“New concept, you can steer with the wheels — ESC steers with the brakes,” said Continental's Headley. “This adds to the stability for rollover control.” The electric offset or superposition steering adds an angle between the steering and the rack that does not require 42 V power. This allows a fast response and the ability to address trailer stability and split-coefficient stopping.

In most ESC and ABS systems, when the driver stops on a surface that is slippery on one side and has a high coefficient on the other, the system typically recognizes that the vehicle is on a split coefficient surface and reduces the pressure on the high coefficient side and ramps it up slowly to give the driver time to provide some steering input. “With this system, it recognizes and automatically puts some steering input in before the driver recognizes it,” said Hedley. “You can have a pretty significant effect on stopping distance.” Figure 5 shows the ESAS as a part of the electronic stability program (ESP) II.

In the Toyota Highlander system shown in Figure 3, the EPS ECU links via CAN communication to the vehicle's gateway ECU, skid control ECU, and the Toyota hybrid system (THS) ECU. This allows the power steering to react to the VDIM system. The skid control system coordinates the VDIM control. The gateway ECU ties the body electronics system to the EPS to provide a warning lamp indication if the system detects a failure. CAN provides the high-speed communication between the systems. The link between the gateway ECU and the meter ECU that displays the warning lamp is performed with Toyota's slower body electronics area network (BEAN) bus.

In a skid condition, the Highlander Hybrid uses the stored values in the skid control computer. These values have been programmed based on testing during vehicle development for the limits of its handling under normal driving conditions, for example, steering angle, expected range of vehicle raw rate, and acceleration rate. Driving that starts to approach the edge of the known envelope causes the system to proactively apply the brakes and reduce the throttle slightly in anticipation of a potential skid. The regenerative braking in the hybrid system provides even better brake control under these conditions. If the driver oversteers, the VDIM takes away the power steering from the wrong direction (against the skid) and reinforces the steering in the right direction to encourage the driver to make the correct decision. This is known as cooperative steering control.

## MORE ELECTRONIC STEERING OPTIONS

Since steering is such a critical safety factor, several approaches are being pursued that use advanced electronic techniques.

A concept that Continental is developing is electrically actuated rear steering. As shown in Figure 6, the active tie-rod electrically lengthens or shortens the tie rod to provide a couple of degrees for stability improvement at the rear wheels. This kind of system can also be used for some improvement in parking assist. Because it lengthens or shortens the tie rod to obtain just a few degrees of steering, the amount of power required for the motor is much smaller than one used for front wheel steering and the system can easily be implemented with standard 12 V power.

With Continental's ESAS and rear wheel steering, dynamic steering, such as lead steer, can be performed. If the driver is in a situation where the wheel needs to move quickly, the system can provide extra steering capability based on the maneuver. If the driver steers one way and back in the other quickly, it significantly reduces the effort in an evasive maneuver.

The use of ultracapacitors to handle peak loads on the power network including EPS could offer some design options in the future. BMW's active hybrid drive concept is based on an active transmission and ultracapacitor technology. The system has an electric power unit with integrated power electronics providing generator, motor and starter functions. The electrical system powers the normally belt-driven accessories, such as the power-steering pump, brake booster and air-conditioning compressor. Ultracapacitors provide energy storage and boost performance for the system. Figure 7 shows the system architecture.

With new approaches to rear wheel steering, supplement energy capability from ultracapacitors, and other system improvements in sensing, power and control, EPS should appear on far more vehicles in the future. “I would personally expect to see it on more vehicles down the road,” said Toyota's Lee. “I think from a fuel economy perspective, it has many, many benefits, and from a longevity perspective it has many, many benefits.” With the Prius being one of today's more complicated electronic control vehicles and its reliability history, Toyota has shown that adding electronics can be done without sacrificing reliability.

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