ELECTRIC POWER ASSISTED STEERING SYSTEM FOR AUTOMOBILES

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Summary

Electric Power Steering for automobiles is primarily an energy saving scheme. It is a recent innovation, which is on the verge of being introduced into automobiles throughout the world. In a few years, it is expected to be in widespread use, just to cut down the energy usage in modern vehicles, if for nothing else. Further advantages may include enhanced flexibilities in the location of the steering system, the tuning of the steering system to cater to the needs of a specific automobile or an individual driver and

the reliability which are currently lacking in the hydraulic assisted power steering system. This chapter starts by tracing the history of developments in the steering systems for automobiles. It then describes the mechanisms involved, and the nuts and bolts of the all electric power steering systems for automobiles. Actuators, sensors and controllers that make electric power steering a reality in modern automobiles are described subsequently.

1. Introduction

The steering system of an automobile serves two main functions: firstly it allows the driver to make the vehicle follow a desired path or trajectory without requiring excessive physical effort and secondly, it assists the driver to judge the driving conditions by allowing some feedback. The latter is a subtle aspect of the steering system, with the driver in the feedback loop striving to minimize the error which the vehicle may have from the desired path.

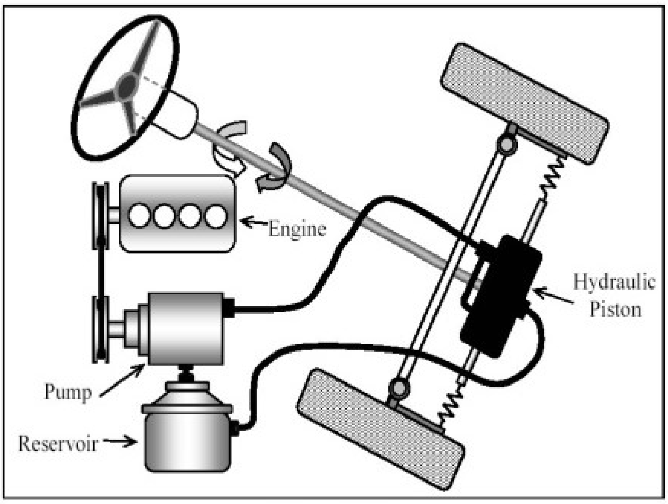

Figure 1(a)

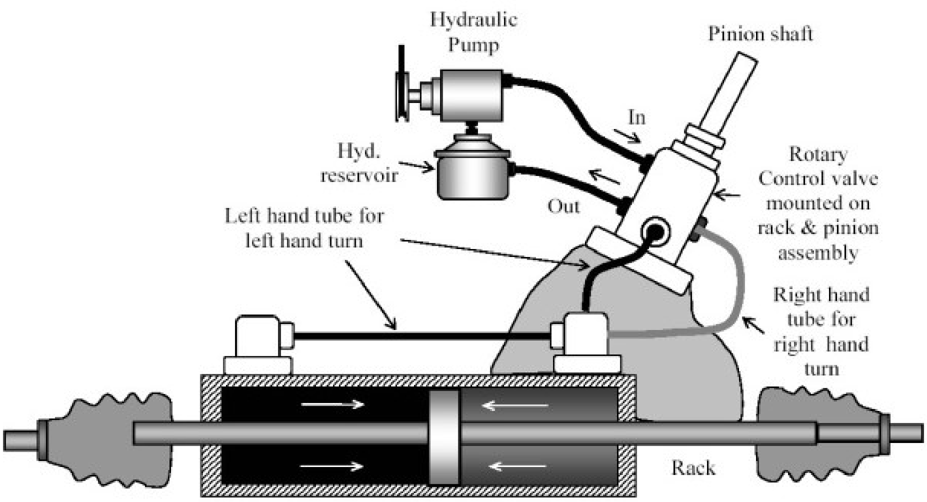

Figure 1(b)

Figure 1: Functional schematics of a hydraulic power assisted steering systems (HPAS)

The hydraulic steering system of present-day automobiles which appears so natural and appropriate, took nearly 50 years to mature after the first introduction. Prior to this time, drivers struggled to maneuver the vehicles for parking, at low speed. At high speed, there was also the problem of finding the right sensitivity and stability. As engine power increased and vehicles grew larger, the effort required of the driver to steer the vehicles satisfactorily became nearly of superhuman proportions. During World War II, this was the realization of many drivers who maneuvered sizeable vehicles in rugged terrains. Efforts to introduce power assisted steering began in earnest immediately after the war. Generals Motors in the USA, and Bishop in Australia developed and introduced the first hydraulically assisted power steering system in the 1950s.

The early hydraulic systems used re-circulating ball steering coupled with a belt driven hydraulic pump. The hydraulic pressure created with rotary vane pump reduced the steering effort required by the driver to overcome the rack load on the steering system. This also provided for better steering stability at high vehicle speeds, since the driver had hydraulic pressure appropriately reduced, assisting in the control of the linkages at all times.

A second system, a rack and pinion steering system (see Figure 2), was developed and used in many lighter and sportier vehicles. Even though no power assistance was required for these types of vehicles for many years, eventually they too started to use hydraulic power assistance.

In a hydraulic power steering system, a hydraulic pump coupled to the engine shaft supplies the necessary oil pressure to either side of a valve, as indicated in Figure 1. When the steering wheel turnes clockwise or counterclockwise, oil pressure builds up, more on one side of the valve than the other (see Figure 1(b)), thus assisting the turn. In the straight-ahead position, the pressure on both sides of the valve is the same, thus neutralizing any assist. Once a turn is completed, the control valve opens a return passageway that allows the oil to return to the reservoir, allowing it to circulate through the system again.

The HPAS has evolved over a long time and automotive engineers have done a superb job in creating systems tailored for all weight, size and power classes of vehicles. However, numerous shortcomings and disadvantages plague the HPAS. Even though the power to weight ratio of the HPAS is very good, the continuous and parasitic power loss due to the hydraulic pump continuously running and maintaining the oil pressure by throttling is a major source of power inefficiency.

This loss may be from nearly 15% of engine power for small automobiles to about 10% for larger vehicles, continuously, regardless of whether steering is used or not. Very often an HPAS can therefore not be viable for small cars. It should be noted that the maximum power assist is required at low speed, for cornering and parking. If the continuous waste of the power of the engine is prevented, the fuel efficiency of the whole automobile can be increased by at least 5%. This level of energy saving has a quite significant effect on the overall energy usage by all the automobiles of the world, leading to justifiable environmental benefits.

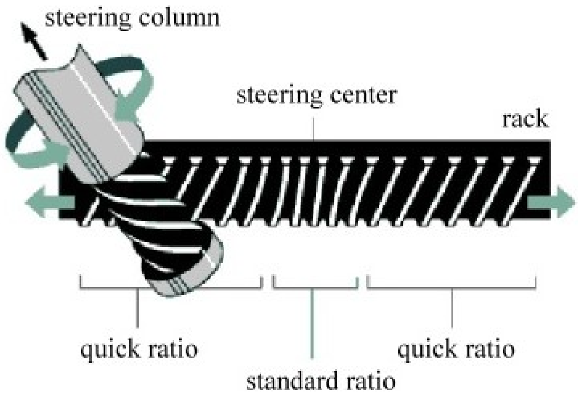

Figure 2: The rack and pinion of an HPAS; Source, Honda NSX.

Hydraulic systems are also a complicated mix of maintenance-intensive and expensive components which are prone to leakage. They also need special considerations in layout and harnessing. Yet another concern is the lack of flexibility of the HPAS, which is constrained in terms of location and space as a result of the belt drive coupled to the engine and the fluid supply hoses to the control valve.

Nearly 50 years since the first introduction of hydraulic power assisted steering, another technological leap is taking place in the area power assisted steering. This involves replacing the hydraulic system with an all electric system in which power is delivered to the rack and pinion of the steering mechanism only when required (i.e., on demand). In this electric power assisted steering (EPAS), an electric motor drives the rack and pinion arrangement to steer the vehicle using power from the battery, as illustrated in Figure 3.

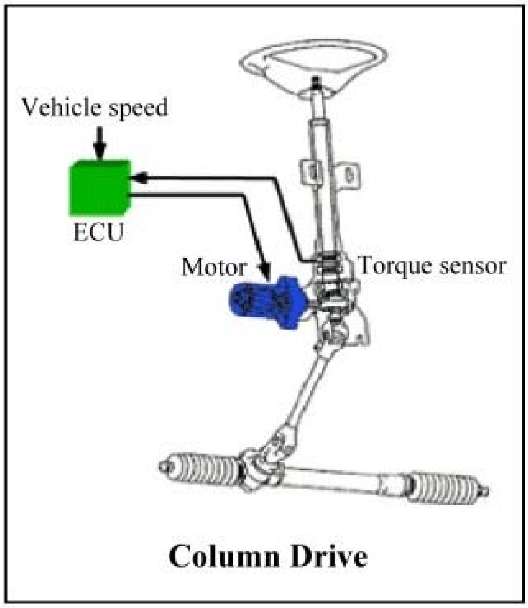

Figure 3: Illustration of an EPAS. Courtesy Koyo EPAS, Japan

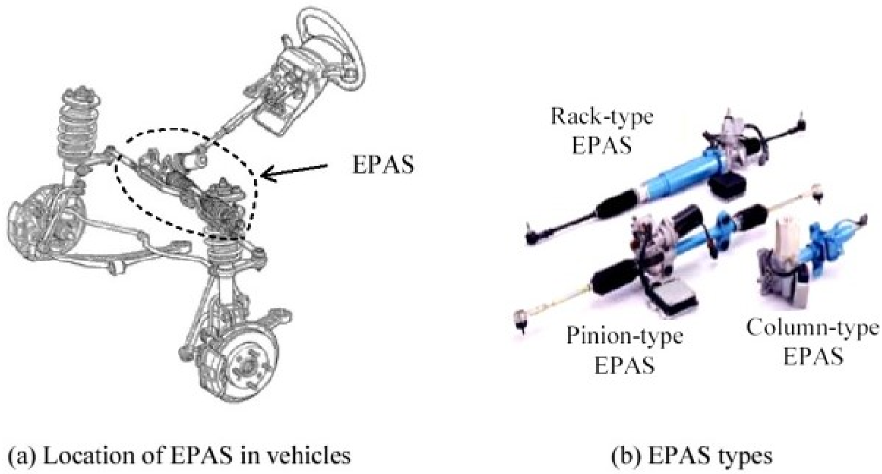

Figure 4: (a) Location and (b) types of EPAS systems; source: Koyo EPAS, Japan

Little power is used or wasted when the vehicle is running at a reasonable speed or when steering is not required. The constant parasitic loss of the HPAS is thus eliminated. The battery supplies all the steering power needed for cornering or parking at low speed. The operation of the EPAS is achieved by firstly sensing the amount of effort, or torque, applied to the steering wheel by means of a torque sensor. This torque sensor is easily incorporated within the steering column. An electric circuit is able to relay this information into an electronic control unit (ECU). The control algorithm generates a signal that drives the electric motor to provide steering assistance. The power to the motor is from the vehicle battery, and it is controlled electronically without incurring much loss.

Column-assist type (CC-EPAS) systems were the early systems introduced by Koyo in 1988 for larger automobiles. In this system, a brushed DC motor was integrated in the steering column. The motor was located in the passenger compartment. The recent trend for light and subcompact vehicles is toward pinion-assist (P-EPAS) which has higher motor output and can be located in the engine compartment.

The EPAS systems can be extremely compact, light and require little maintenance. They are easily designed and packaged in modular forms, and they can be easily tuned to requirements of a particular size and type of vehicle, and even to the driver's habits. This type of steering assistance becomes viable even for the smallest of automobiles.

During the past ten years, EPAS has been introduced in gradually increasing numbers. Although electric power steering systems offer significant advantages over their hydraulic counterparts, electric motor technology and controls had not reached the point where they could be used in this application until just recently. In the mid-1980's, for example, TRW had a working electric power steering system but it had the unfortunate tendency to completely drain the battery during a single parking maneuver. New generations of materials, sophisticated computerized electronic control systems and advancements in power management have all contributed to making electric power steering assist a reality.

The 1990 Acura NSX was the first production vehicle to use a fully electronic steering rack, a unit from Showa. The 2000 Fiat Punto used Delphi's E-STEER electric power steering system in the first high-volume production application. Volkswagen's 2001 Lupo 3L TDI can be optioned with E-STEER for 1.3 miles-per-gallon better fuel economy. Honda's Insight, Prelude and S2000 use Showa electric power steering and the new MGF also uses EPAS. The Saturn Vue will use a unit from Koyo.

Honda Insight EPAS

Figure 5: Example of an EPAS from Honda

Other issues are also driving the move toward electric assist. In electric and hybrid vehicles such as the Honda Insight, the engine does not run continuously so electric power steering is the only possible route. Programmable steering response also allows additional return-to-center action, freeing chassis engineers to pursue more aggressive wheel alignment specifications and suspension geometries. Similarly, the units can be programmed to eliminate steering wheel kickback over rough surfaces. Finally, maintenance is eliminated for the life of the vehicle and the unit is readily recycled.

Fuel economy improvements with electric power steering vary by vehicle and engine size, but normally vary from 1 to 3 miles per gallon. That is a very large savings obtainable by OEMs without requiring extensive drive-train or combustion engineering.

Electric power steering has now become such a compelling technology that 30% of the world's vehicle production (approximately 20 million units) will use it by the 2003 model year. Many industry experts predict that hydraulic power steering will disappear from new cars within five to seven model years.

2. Essential Components of an EPAS System

Details of EPAS system designs differ amongst automotive manufacturers; however there are certain components that are intrinsic. These are:

1. Torque sensor
2. Electric motor
3. Rotational angle sensor
4. Controller
5. Vehicle speed sensor
6. Coupling between motor and steering mechanism

The torque sensor is perhaps the most important component; it measures the effort being applied by the driver to steer the vehicle. The torque sensor output is then used to drive a motor to reduce the effort, while achieving the desired steering. The motor may be located at a number of locations to achieve this. The purpose of the motor controller is essentially to control the torque delivered to the steering mechanism. The vehicle speed must be used to adjust the sensitivity of the torque controller. The angle of rotation of the steering wheel must also be used to adjust the sensitivity and the performance around the null position of the steering wheel.

Electromechanical specifications of a typical pinion type P-EPAS system from Koyo are reproduced in Table 1.

Items	**Specification**
Rack force	7747 N
Rack stroke	144 mm
Stroke ratio	45.335 mm/rev.
Rack & pinion Module Number of teeth	 2.3 6
Reducer Type Reduction gear ratio	 Worm & Resin wheel 15.1
Motor Type Rated voltage Rated current Rated torque Rated rotational speed	 Brushed DC motor 12 V 65A 3.4 Nm 1,180 rev/min

Table 1: Specifications of Koyo EPAS system

3. Torque Sensors for EPAS

Being a torque controlled system, the EPAS requires a sensor for the rotational effort or torque that the driver exerts on the steering wheel in order to steer the vehicle. This is the heart of the EPAS system. The sensor output signal is then passed on to a motor controller to develop the torque that is *required* to assist the driver. The magnitude of the required torque is determined by the driver who is in the control loop. The relationship between the output of the torque sensor and the developed torque of the motor should be linear. The driver responds to the movements that the vehicle makes based on his/her visual observation and perception of vehicle movement received through the steering wheel.

The main component of the torque sensor is the torsion bar which registers a differential (or relative) angular displacement between the two ends of the bar. The amount of torsion of the bar or flexing, $\Delta\theta$, (typically ≈ 1.8°) as indicated in Figure 6, can be picked up as an electronic signal in various ways. Accordingly, a number of types of torque sensors have been developed. A brief description of torque sensor types follows.

The relative displacement $\Delta\theta$ of the torsion bar when torque is applied at the two ends is given by,

$$\Delta\theta = \frac{32T_{\mathrm{L}}L}{\pi D^4 G} \text{ rad,} \tag{1}$$

where

T_{L} = applied torque
L = the length of the torsion bar
D = diameter of the bar
G = shearing modulus of elasticity

Ideally, the torsion bar is part of the steering rod between the pinion and the steering wheel, thus a wide choice is available for its location. Its aim is to develop a torsion ($\Delta\theta$) of about 1.8 degrees for a sufficient sensor output signal with high signal to noise ratio, without compromising the mechanical strength of the steering rod. It should be noted that both ends of the torsion bar are free to rotate by about two revolutions, which means that all the electronics attached to the discs at the two end much be connected to power supplies and other external circuits through flexible cables. In addition to the relative displacement angle $\Delta\theta$, it may also be necessary to sense the absolute angular position and velocity of the steering wheel.

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Biographical Sketch

Dr. M. F. Rahman graduated from Bangladesh University of Engineering & Technology, Dhaka, Bangladesh with a B.Eng (Elec.) Honours degree in 1972. He then proceeded to U.K, where he obtained his M.Sc. in Power Electronics and PhD degrees in 1975 and 1975 respectively from the University of Manchester Institute of Science and Technology (UMIST). Early in his career he worked for the General Electric Company, U.K, developing microprocessor and programmable logic controller based (PLC) automation equipments for metal processing industries. He developed the first microprocessor based sheet metal classifier system for a large aluminum sheet manufacturer. He also developed first PLC based automation system for charging a steel mill furnace. He later joined the National University of Singapore where taught a number of subjects dealing with different types of electromagnetic actuators and their controllers. Here his research led to the development of a new micro-stepping technique for stepper motors. The method allowed the step size of variable reluctance type stepper motors to be reduced by 30-100 equal micro-step angles. Dr. Rahman joined the University of New south Wales in 1988, where he introduced new laboratories and teaching subjects in power electronics, drives and motion control. He helped develop a new torque control technique called Direct Torque Controller for the interior permanent magnet synchronous motor. Dr. Rahman is currently an Associate Professor at UNSW and is a Senior Member of the IEEE. He has served IEEE in a number of roles, for which he received a Third Millennium award in 2000. Dr. Rahman has contributed invited chapters in three internationally published books on automation, power electronics and electrical drives.