Electric Power Steering with Permanent Magnet Synchronous Motor Drive Used in Automotive Application

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***Abstract*-In this paper, an intelligent electric power steering system use with Permanent magnet synchronous motor drive is proposed It is to replace a traditional hydraulic power steering system and implemented in a real light hybrid electric vehicle for automotive application. Some control Technique is applied to yield basic assist logic, return compensation logic, damping compensation logic, and inertia compensation logic in an assist steering system according to steering wheel angle and vehicle speed. The PMSM drive in an EPS system can be considered as a torque amplifying and tracking system. When the driver of the vehicle moves the steering wheel, a torque sensor in the steering mechanism sends a torque signal to the EPS controller. The DSP inside the EPS controller receives the torque input and sends it to a torque command algorithm. The torque command algorithm processes the torque input, along with other inputs, such as vehicle speed, motor speed, and generates a torque command to the PMSM drive subsystem. The PMSM drive controls the PMSM motor to generate an output torque that tracks the desired torque demand. In this paper Section 1 describes Introduction, Section 2 describes EPS system description &hardware, Section 3 describes control strategy& Section 4 describes conclusion.**

***Keywords*-Electric power assists steering, Permanent magnet synchronous motor (PMSM).**

I. INTRODUCTION

In past years without power steering technique, although large reduction ratio can alleviate the driving torque of drivers, it is still very tiring in fact. Thereafter, hydraulic power steering (HPS) improves this problem. In a hydraulic power steering system, driving a steering wheel is to control a pressure valve, which causes straight line motion of a rack mechanism to change tires direction through link sticks. However, environmental consciousness has been paid attention in nowadays with technique progress. Even though the HP Possesses large power and smooth output, there are still some drawbacks, such as (1) Pipes may leak. (2) Hydraulic oil may deteriorate since rising temperature when pipes and hydraulic oil rub against. (3) Check and change power steering wheel oil on a regular time. (4) Pipes are complex. (5) A hydraulic pump, a hydraulic oil storage tank, and pipes, etc, increase weight and occupy space. (6) Extra engine power is needed to drive a hydraulic pump, i.e., oil consumption will be increased. (7) A holding pressure is necessary when a vehicle moves on a straight line. The EPS System has a compact structure compared with conventional one, and it is an on demand system that operates only when the steering wheel is turned. Besides, the EPS has more flexibility by the advantage of electronics control of the motor. It is easy to adjust the steering system. Electric power steering (EPS) does not posses above drawbacks of HPS. Additionally, there are some advantages, such as, (1) According to different driving modes, different assist power can be provided. (2) The assist motor only works in turning assist. In an EPS system, the motor is mounted on a steering column. Motor torque can be amplified and delivered by a gear box in order to alleviate drivers' torque. In past years, there are many literatures about the EPS system. Generally, there are two research topics. The first is motor controller design or EPS mechanism design. The second is the EPS strategy analysis, which is also the priority in this paper. In general, the EPS control strategy includes the basic assist logic, the damping compensation logic, the return compensation logic, and the inertia compensation logic [1-5]. The main steering strategy is the basic assist logic, other compensation logic are auxiliary to compensate insufficient return, excessive return, and heavy steering since drive the steering wheel very quickly. Each compensation logic is independent and there is a corresponding look-up table. Input signals include the vehicle speed, the steering wheel angle, the steering wheel angular velocity, the steering wheel angular acceleration, and the drivers' torque. It can adjust compensation gains immediately to complete EPS assist characteristics.

A Permanent magnet synchronous motor (PMSM) has been applied to the performance improvement of EPS. Because PMSMs have many advantages such as high efficiency and high torque per rotor volume, they are especially suitable for automotive applications where space and energy savings are critical.

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II. EPS SYSTEM DESCRIPTION

According to the motor mounted location, the EPS system can be divided into three types, which are a column assist type, a pinion assist type, and a rack assist type, respectively. There is serious noise request in the column assist type since the type is closest to drivers than other two types. Oppositely, the column assist type is farthest to the engine and chassis than other two types. The request of water and heat proof can be reduced. The pinion assist type is better than the column assist type in shock and noise. An advantage of the rack assist type is that the assist motor can be mounted on any locations of the rack Therefore; the rack assist type has the elasticity of mechanism integration in chassis. In applications, the column assist type is popular and small power nowadays. For this reason, this research is based on the column assist type. In the column type EPS system, the PMSM is linked to the steering shaft via a reduction gear, so that the motor vibrations and torque fluctuation are transferred directly through the steering wheel to the hands of the driver.

A. *EPS hardware system structure*

Figure 1 shows the hardware structure of the EPS system. Two sensors which are an angle sensor and a speed sensor are applied to detect the steering wheel angle and the vehicle speed, respectively. The two sensors return feedback signals real-time to the EPS controller for the assist strategy analysis. Through the closed-loop control of the assist motor, the assist motor can provide desired output torque. Thus, the produced motor torque combines with the driver torque to drive the rack. The PMSM driven EPS system is modularized into components as Fig. 1. Each module is modeled by its own suitable domain descriptions for reflecting specific characteristics.

. **Circuit-domain**:
The PMSM electrical parts and inverter are represented by the interconnection of circuit elements.

. Equation-domain:
The system mechanisms integrated with PMSM mechanical parts are described by differential or algebraic equations.

. **Function-domain**:
The controller which includes PWM generators is represented in their functional forms that describe the behavioral properties.

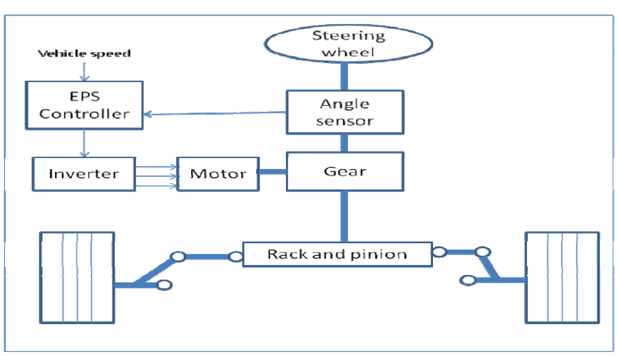

Figure 1: EPS hardware structure

There are many features developed for the EPS system. The magnitude, the direction, and the timing of torque output control of the assist motor are especially important. Hence, in order to develop the control logic for the EPS system, it needs to build the steering system model previously. Chen and Chen [1] applied Newton's Law to build the dynamic model of every parts of the EPS system. Parmar and Hung [2] utilized the Lagrange's Equations to construct the dynamic equation of the EPS system. Liao and Du [3] tried to combine the Matlab/Simulink and Adams to simulate the behavior of the vehicle and used the co-simulation technique to understand the effect of the EPS system on the vehicle motion. Choi et al. [4] associated SimPowerSystems with Matlab/Simulink to describe the effect of power electronics on the EPS system. Furthermore, the assist power is provided by an electric motor and affects the steering feel directly. Kurishige et al. [5] and Pang et al. [6] introduced motor control methods for avoiding the fluctuation, from the rotation motor, to influence the steering wheel and prevent to the driver from unfavorable steering feel. For control logic design, references [1-5] specified some methods that can improve the steering dynamics in some special situations while driving. They aimed to research and develop various control logics such as return compensation logic, and damping compensation logic the major purpose of this research is to develop an EPS control logic which is composed of base assist, damping, return, inertia, and impact compensation logic with the aid of Matlab/Simulink and CarSim. In addition, this research proposes a new method to improve the compensation performance. It employs the steering angle signal and the vehicle speed signal into the control logic to tune the compensation gain immediately.

III. CONTROL STRATEGY

The primary goals of the EPS system are to reduce the steering torque exerted by the driver and to better the Steering performance. It not only improves the steering feel but also increases the driving pleasure. This research Integrates the base assist, return, damping, inertia, and impact compensation logic into the EPS control loop. The Overall structure of the control logic is shown in Fig. 2

A Base assists logic

The major object of the EPS system is to provide a proper amount of assist torque by the electric motor to reduce the effort of the driver when the vehicle is cornering. For generating a suitable torque output from the Motor to assist the driver, a base assist map shown in Fig. 2 is needed. According to the map, the core controller of the EPS system receives signals from the torque sensor and the vehicle speed sensor and calculates a suitable Amount of assist gain to output to the motor controller. Therefore, the motor can provide a proper torque to assist the driver to turn the steering wheel.

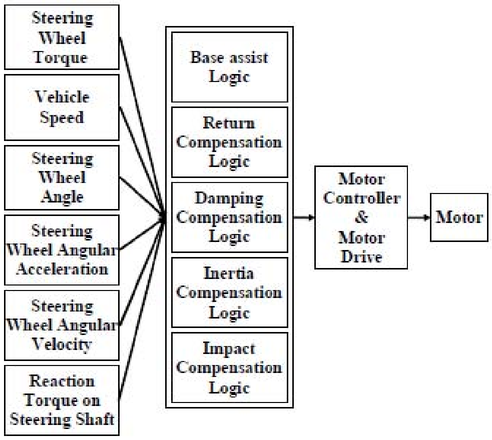

Figure 2. Block diagram of EPS control system.

B Return Control logic

The EPS system can overcome drawbacks associated with conventional one. One of the advantages is that the EPS could improve the return-to-center performance, called return ability, which is an important feature while Driving. When the front wheels are steered, some energy would store in the mechanical structure of the steering System. The energy would produce a torque which tends to return the steering wheel to the center. In some driving Cases, such as low speed driving, the steering wheel may not be able to return to center because of the friction in the Road wheel and the steering system. For this reason, the return control logic has been introduced in the EPS system. It takes the advantage of controllable torque of the electric motor to improve the return-to-center performance and the vehicle dynamics. In this paper, the steering angle has been adopted as a major signal to control the assist motor to rotate the steering wheel to the near center position when the driver has his/her hands off the steering wheel. Besides, this paper attempts to take the steering wheel angular acceleration and the vehicle speed as compensation signals to enhance the performance of steering return ability. The compensation maps are established to tune the control gain according to the steering wheel angular acceleration signal and vehicle speed signal as shown in Fig. 3. The steering wheel angular acceleration gain is in nonlinearly inverse proportion to the absolute value of the steering wheel angular acceleration, and the vehicle speed compensation gain decreases with the increase of the vehicle speed. The return performance will be better based this method. During the high speed operation, the aligning torque is significant large, which might make the steering wheel have an overshoot response. This characteristic leads to generate an unexpected yaw motion of the vehicle.

C Damping, Control logic

The damping compensation logic has been applied in the EPS system to absorb the overshoot and alleviate The unexpected yaw motion. This paper tries to take the steering wheel angular velocity as a main control Objective by means of the closed-loop technique. The logic generates a gain, which is opposite to the direction of the steering wheel angular velocity, as a reference of the motor current control loop. The motor torque resists the aligning torque from road wheel against the direction of the steering wheel motion. In this situation, the motor seems to be a buffer to mitigate the severe return action. Adding the steering wheel angle signal and the vehicle speed signal as the reference of compensation strategy can help tune the control gain to make the performance Preferable. The steering wheel angle gain increases with the increase of the steering wheel angle, and the vehicle speed gain increases with the increase of the vehicle speed. For most of driving conditions, the base assist logic is almost able to cover all of assistance requirements according to the vehicle speed and the diver’s torque input.

D Inertia Control logic

when the driver turns the steering wheel rapidly, the heavy steering feel is produced by the inertia of the steering mechanism. It is an uncomfortable steering feel. In this situation, the base assist logic may be no longer enough to satisfy the steering demands. It is the major reason why the EPS control system needs the inertia control logic. The heavy handling feel is caused by the large steering wheel angular acceleration, so this approach utilizes the steering wheel angular acceleration as the main command, and takes the vehicle speed and the steering wheel angle as the auxiliary signals. This method can produce more assist torque to eliminate the heavy handling feel when the driver turns the steering wheel quickly. In addition, the steering wheel angle and vehicle speed have been used to compensate the inertia control performance. The steering wheel angle gain is in nonlinear proportion to the steering wheel angle, and the vehicle speed compensation gain increases with the increase of the vehicle speed. Fig. 3 shows the schematic diagram of the control logics of return, damping, and inertia.

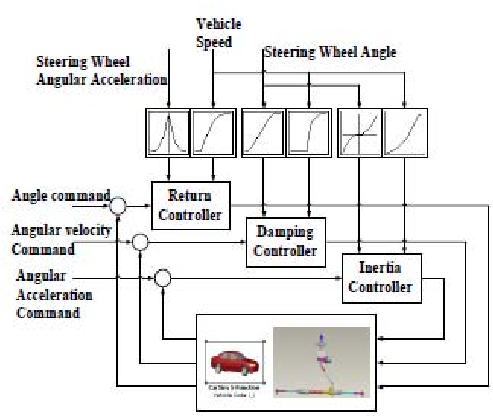

Figure 3 Control logics of return, damper, and inertia.

5. Impact Control logic:-

When a vehicle passes through an uneven road surface, an oscillation may be occurs on the steering wheel. The oscillation normally takes place at low speed stage. In fact, it is an uncomfortable feeling of handling and may make the driver nervous during oscillation period. To reduce the effect from the road surface, this paper proposes a new method to achieve this function by means of estimating the reaction torque on the steering shaft (RTSS). The RTSS estimation method had been specified in reference [1] clearly. In this research, it takes the advantage of the RTSS estimation method and calculating the variation of the RTSS value. If the variation value increases more than the threshold, the control logic would generate a command to enable the impact compensation loop. The impact Compensation loop will feed back the steering wheel angular velocity signal to control the assist motor. The motor control loop will calculate a suitable current command to motor and then the motor produces a suitable torque output to the steering system. The motor, in this case, alleviates the oscillation of steering wheel like a damper. Fig. 4 depicts the schematic diagram of the impact compensation logic.

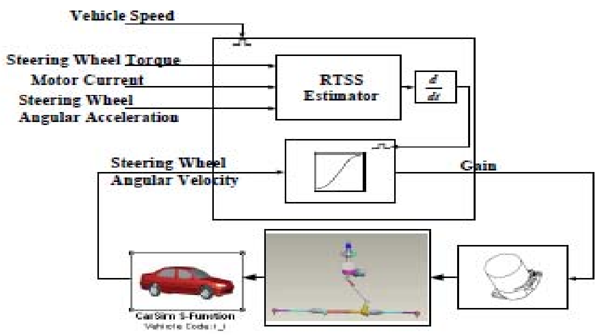

Figure 4. Schematic diagram of impact control logic

IV. CONCLUSION

This Literature survey is Propose intelligent EPS system with a PMSM motor. The new EPS controller and the new motor have low energy consumption and small volume. Therefore, the proposed EPS system is very suitable to mount on vehicle for saving energy. In control strategy some logic such as basic assist logic, the return compensation logic, the damping compensation logic and inertia compensation logic and impact control logic are discuss. The main advantages in this Literature survey are that the smooth driving feeling can be obtained.

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