Development of Low-Cost Electronic Control Unit in Electric Power Steering

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***Abstract*—Electric power steering system (EPS) uses an electric motor to provide essential control to the driver. When the driver turns the steering, the control unit reads the torque sensor, which measures how much effort, the driver is applying into it and brings the electric motor into play till the effort is reduced to zero. The vehicle runs on a brushed DC motor, powered by 12V batteries and controlled from an ECU. From the microcontroller point of view, not only must it be functionally acceptable, it must be able to withstand the harsh environment. In this project an effective pulse width modulation control strategy has been designed to adjust the motor torque and current in order to increase the availability range. The new electronic control unit has been developed using microcontroller MPC5604P which is cost effective compared to the existing microcontroller.**

***Index Terms*—EPS: Electric Power Steering ECU: Electronic Control Unit EHPS: Electric Hydraulic Power Steering RPM: Rotation per Minute PWM: Pulse Width Modulation**

I. INTRODUCTION

In the present-day world, the term power steering is quite common in higher priced vehicles. However, when the lower priced vehicles are considered for example TATA NANO, they still run on manual steering only. Power steering has several advantages over the manual steering. Few of them being, (1) Increase in fuel efficiency (2) Provides greater control to the driver of the vehicle (3) Provides comfort to the driver of the vehicle. Hence in order to incorporate power steering into the lower priced cars, an Electronic Power Steering with a low-cost Electronic Control Unit is required. Therefore, there arises a need for the Design and development of low-cost electronic control unit in the Electric Power Steering mechanism.

Electric power steering is designed to use an electric motor to reduce effort by providing steering assist to the driver of the vehicle. Sensors detect the motion and torque of the steering column, and a computer module applies assistance torque via an electric motor coupled directly to either the steering gear or steering column. This allows varying amounts of assistance to be applied depending on driving conditions

The Electro Hydraulic Power Steering (EHPS) is an advanced system that uses conventional hydraulic power steering with an electric motor-driven hydraulic pump. The Electric Power Steering (EPS) is the latest system in which the electric motor is attached directly to the steering gearbox without a hydraulic system. Sensors detect the motion of the steering column and a processor module applies assistive power via an electric motor. With electronic systems becoming more and more common in cars, EPS is active only during the actual steering process. The EPS system shown in the fig 1.1 consists of a torque sensor, which senses the driver's movements of the steering wheel as well as the movement of the vehicle. An ECU, which performs calculations on assisting force based on signals from the torque sensor; a motor, which produces turning force according to the output from the ECU and a reduction gear, which increases the turning force from the motor and transfers it to the steering mechanism.

Fig. 1: EPS system

Generally, with column-type EPS systems, there is less space available for the steering column to absorb energy in the event of an accident because the EPS system is located on the column. The column assembly of this EPS system has inner and outer column sections like a conventional EPS. In addition, for safety in accidents, it has a mechanism to soften its collapse, a convoluted tube to absorb the driver's energy, and a device that allows the lower bracket to absorb energy [5].

Because the steering wheel and reduction gear in a column-type EPS are located close to each other, sound produced in the reduction gear is directly transferred to the vehicle's interior. To reduce this noise, the worm wheel gear is made of plastic.

II LITERATURE SURVEY

Enormous literature is available regarding the power steering in the form of books and research papers. Some of the works are condensed and briefly presented here.

The MCU and power stage design specifications are directly affected by the motor type and its control strategy. A simple PM (permanent magnet) DC motor can be controlled from an 8-bit average performance MCU. An AC motor's voltage per frequency (V/F) or speed requires a higher performance 8-bit MCU. An AC motor drive strategy that adjusts the motor's current vector to control torque (Vector Control) usually requires a high performance 16 bit or 32-bit MCU that incorporates precision timer functions. [1]

Electric power-assisted steering represents the future of power-assisted steering technology for passenger cars and is already beginning to appear in high-volume, lead-vehicle applications. EPAS is a classic example of a smart actuator operating under feedback control. The key components of an EPAS system (combined torque and position) sensor, an actuator (electric motor), an electronic control unit (ECU), and control and diagnostic algorithms implemented in software. It eliminates the connection between the engine and the steering system. One part of the EAS family is the Electrically Powered Steering 'Column Drive EPS'. It is a very cost-effective solution in part due to its location in the passenger compartment which enables significantly reduced requirements concerning temperature and sealing in comparison to systems which are installed in the engine compartment. [2]

III ECU COMPONENTS

In this chapter, we discuss the functional block diagram and the components of ECU. The functional block diagram is shown in fig 3.1

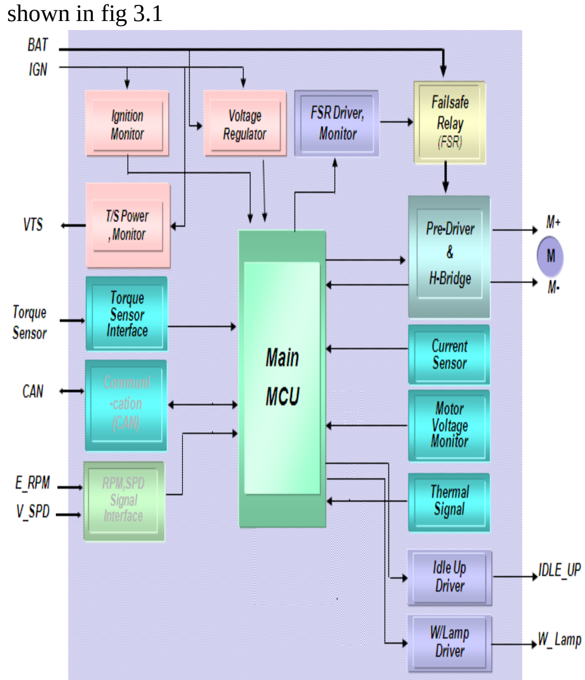

Fig. 2: Functional Block Diagram of ECU

Electronic Control Unit

EPS system provides the ability to steer the vehicle with less torque. The ECU receives driver requested Torque, Engine Speed, Vehicle Speed judges the current vehicle condition, determines the assistance power required and actuates the EPS motor. If the steering wheel is turned and held in the full-lock position and steering assist reaches a maximum, the control unit reduces current to the electric motor to prevent an overload situation that might damage the EPS Motor. The control unit should be designed to protect the EPS Motor against temporary higher voltages. The ECU should be capable of self-diagnosing faults by monitoring the EPS system inputs, outputs, and EPS Motor driving current. If any fault occurs, the control unit should switch ON the EPS malfunction warning lamp over CAN bus to alert the driver. The control unit shall also have the failsafe strategy to revert back to manual steering

The three primary roles and corresponding functions of the ECU in EPS systems are:

1. Assurance of comfort
   - Power steering function (Motor current control function)
2. Assurance of safety
   - Self-diagnosis and failsafe functions
3. Assurance of convenience
   - Communication functions

EPS Motor

Motor is the actuating unit of the EPS system. The EPS ECU analyses the torque sensor inputs, determines the required EPS Motor output torque and drives the EPS Motor. The EPS Motor should be capable of rotating in clockwise and anti-clockwise direction. The EPS Motor in normal and failure mode should not lead to mal-function of the ECU due to Back EMF. Design of the EPS Motor should be in such a way that losses are minimal. The EPS Motor has thermal cutoff provision to avoid burning due to overheat.

Motor Control

In a steering system, to assist the driver, the DC motor control is required to control the Torque and direction of rotation. Driving a brushed DC motor in both directions, by reversing the current through it, can be accomplished using a full-bridge which consists of four MOSFETs. For ‘forward’ rotation Q1 and Q4 are switched on while Q2 and Q3 are off. For ‘reverse’ rotation Q2 and Q3 are on while Q1 and Q4 are off and shown in the fig 3.

If the upper two MOSFETs are turned off and the lower ones are turned on, the motor is ‘braking’. The motor will ‘coast’ (free running) if all four switches are turned off as shown in the fig 4. In case the motor is in a stalled position, the current will increase drastically. Due to this exceptional increase in current to avoid any damages, the motor is switched into ‘coast’ mode.

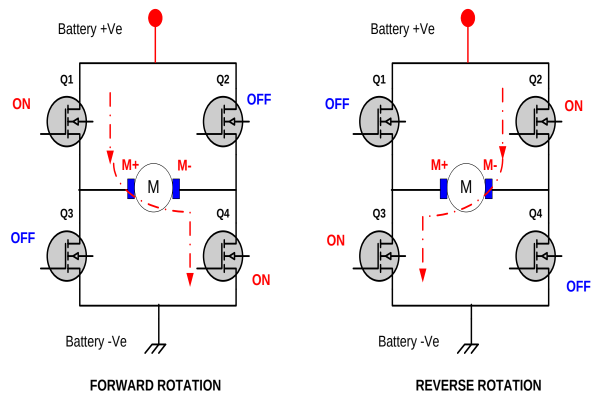

Fig. 3: Forward and reverse rotation of the DC motor

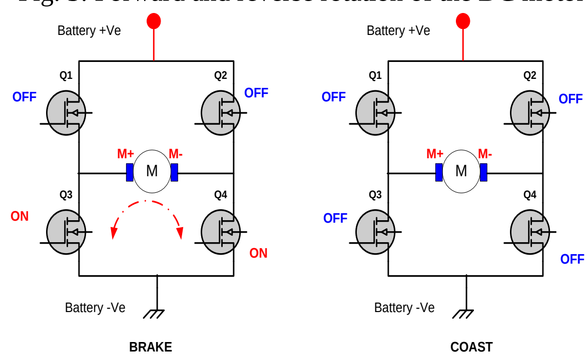

Fig. 4: Brake and coast operation of the DC motor

The microcontroller will calculate the motor current demand according to the required ASSISTANCE TORQUE DEMAND. The power loss in the gear box due to efficiency of the gear box has to be considered, following which the motor current can be estimated. The motor current demand magnitude is limited to a value determined by the drive stage temperature and fast thermal estimator temperature by the diagnostic module.

The Actual current demand is calculated as follows

Actual current demand = Assistant Torque Demand / Motor Torque Constant

$$\text{Assistant Torque Demand} = \left[\frac{\text{Calculated Assistant Torque Demand from Algorithm} \times \dfrac{\text{GEARBOX POLARITY} \times \text{NUM WORM STARTS}}{\text{NUM WORM WHEEL TEETH}}}{\text{GEARBOX EFFICIENCY}}\right]$$

$$\text{MOTOR TORQUE CONSTANT} = \text{MOTOR TORQUE CONSTANT} * (1 + \text{MOTOR TORQUE CONSTANT TRIM})$$

Where,

a. MOTOR TORQUE CONSTANT is a preloaded (pre-defined) constant.

b. MOTOR TORQUE CONSTANT TRIM can be tuned during End of line test and is a signed integer.

c. "GEARBOX POLARITY" is -1 for left hand drive vehicles and +1 for right hand drive vehicles.
d. Gear box ratio is a preloaded constant.

IV. IMPLEMENTATION OF ECU

In this chapter, the implementation of ECU is explained in detail. The block diagram is shown in fig 4.1.

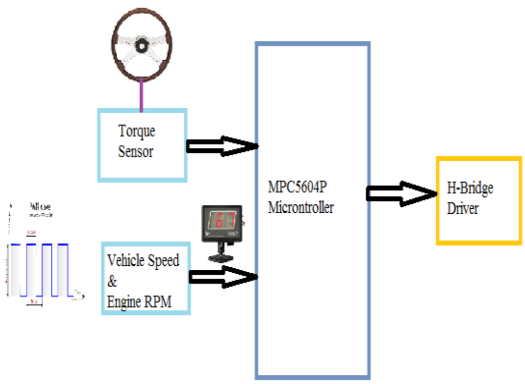

Fig. 5: Implementation of ECU

The ECU forms a vital part in the entire steering system. The ECU implementation block diagram is as shown above. It consists of a Microcontroller MPC5604P, which takes inputs from the Torque Sensor, Vehicle speed and Engine RPM. The output of the microcontroller is connected to the H-Bridge. The microcontroller calculates the amount of the power assist and sends it to the H-Bridge.
The torque sensor detects the twist of the torsion bar and converts the applied torque into an electrical signal. This Electrical signal is fed to the microcontroller where it is compared with the reference voltage range to determine the direction of the vehicle steering. If the voltage range is between 0-2.5V then it indicates that the steering wheel has been turned left. If the voltage range is between 2.5-5V then it indicates that the steering wheel has been turned right. The reference voltage values are as shown in the Table 1.

Table 1: Reference values to indicate the direction of the vehicle steering.

REFERENCE VOLTAGE	DIRECTION
0 – 2.5 V	LEFT
2.5 – 5 V	RIGHT

The other external input to the microcontroller is the Vehicle speed. The Vehicle Speed sensor will sense the Speed of the vehicle and send it in the form of a train of pulses to the microcontroller. This train of pulses is accepted as input by the microcontroller, which is checked with the interpolation table. In the interpolation table the speed of the vehicle is obtained with reference to the number of pulses received. The Vehicle Speed will act as a limiting factor which decides up to what level the steering wheel can be rotated, in other words it decides the angle of rotation.
The microcontroller then gets the angle of rotation for the steering up to which it can be rotated by referring to another interpolation table which is given in Table 2 on the basis of the vehicle speed received. The Microcontroller generates flexPWM signals based on the required and permitted torque, which depends on the torque demand and the vehicle speed.

Table 2: Interpolation table indicating the rotation angle of steering.

Vehicle Speed in Km/hr	Steering rotation angle in degree
2	90
10	80
20	70
30	60
40	50
50	40
60	30
70	20
80	10
90	5
100	2

As shown in the Table 2, when the vehicle speed increases, permissible steering rotation angle decreases. When the car is moving at a higher speed and if it encounters a steep curve, then corresponding required angle of steering cannot be obtained instantaneously. So, we need to reduce the vehicle speed to achieve the required angle of steering.
If the vehicle speed sensor fails for any reason, the engine speed is used as an alternative input. The Vehicle speed will be calculated in the absence of Vehicle speed sensor based on the formula given below.

$$\text{Engine Speed (n)} = \frac{1000 * \text{Vehicle Speed} * \text{Gear Ratio}}{2\pi R}$$

Where,
Gear ratio is a preloaded constant
R is radius of the tyre.

V. RESULT ANALYSIS WITH CASE STUDY

In this chapter different cases of the vehicle movement with respect to the direction, speed and the pulse width of the PWM pulse is discussed in detail as shown in the cases below.

The input to the microcontroller and outputs are as follows:

Pulses obtained from the vehicle speed sensor: The microcontroller generates the flex PWM pulses, whose duty cycle is determined by the speed based on the permissible angle of rotation as per Table 3.2. The duty cycle controls the voltage applied to the DC motor, thus controlling the assist torque.

The input from the torque sensor: The microcontroller decides on the direction of rotation based on the voltage of the torque sensor. Two output pins drive the switches of the H-bridge, so as to drive the motor left, right or in freewheeling mode

CASE 1:
Consider the following parameters
Input:
Direction: Straight
Speed of the Vehicle: 10 km/hr
Output:
From Table 2 permitted rotation 80^0
Torque sensor voltage: 2.5V
Inference: Motor has to run in free mode.

The basic operation of this case is as shown above. The Vehicle is moving in the forward direction [straight] at a speed of 10 km/hr. The vehicle speed sensor generates pulses proportional to this speed. This Speed of 10 km/hr is obtained from the interpolation table which is accessed by the microcontroller. Then the microcontroller will send out pulses with 98% duty cycle which as per the design based on the Speed of the vehicle. These pulses obtained with the duty cycle of 98% from the microcontroller are as shown in fig 6. This forms the input to the DC motor. Since there is no rotation, the H-Bridge switches S1 – S4 and S2 – S3 are all turned OFF. Hence, the DC motor does not produce any assist torque as it is in free running mode.

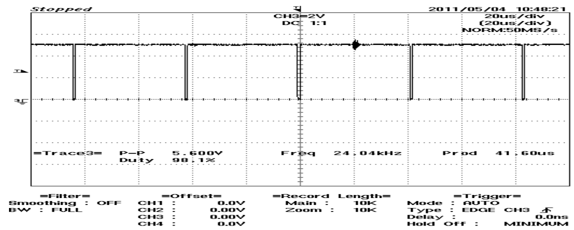

Fig. 6: Flex PWM output of 98% duty cycle and 24 KHz frequency

CASE 2:
Consider the following parameters
Input:
Direction: Right
Speed of the Vehicle: 50 km/hr
Output:
From Table 2 permitted rotation 40^0
Torque sensor voltage: 3V
Inference: Motor moves right.

The basic operation of this case is as shown above. The steering of the vehicle has been turned in the right direction at a speed of 50 km/hr. This Speed of 50 km/hr is obtained from the interpolation table which is accessed by the microcontroller. Then the microcontroller will send out pulses with 50% duty cycle which is based on the Speed of the vehicle. These pulses with the duty cycle of 50% are as shown in fig 8. This form the input to the DC motor. The H-Bridge switches S1 – S4 are turned ON and S2 – S3 are turned OFF as shown in fig 5.2. The motor produces the necessary assist torque.

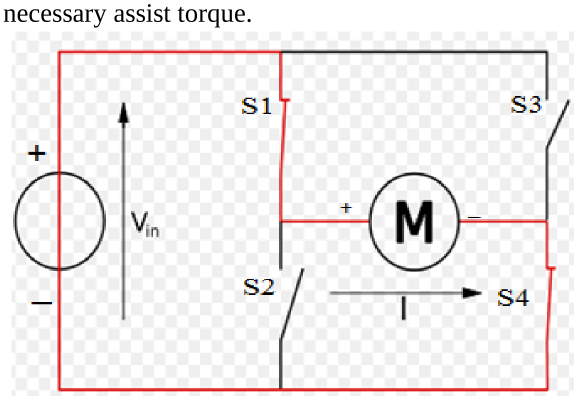

Fig. 7: H-bridge operation (Motor moves right)

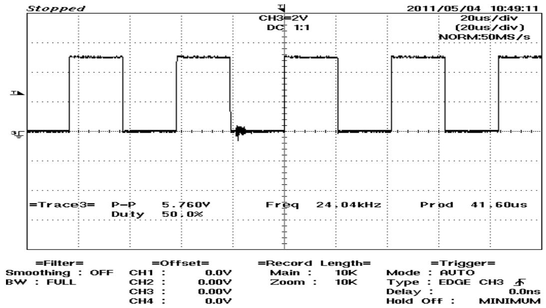

Fig. 8: Flex PWM output of 50% duty cycle and 24 KHz frequency

VI. CONCLUSIONS

In this project a low-cost ECU has been developed to replace the existing ECU unit. The ECU has been tested for different conditions and found to operate satisfactorily. Hence, the concept of power steering can be made available not only to the higher priced vehicles but also to the lower priced cars using this design and development. As a result, the driver can be benefited by the advantages of power steering like better comfort, lesser fatigue, greater control over the vehicle and also reduction in fuel consumption.

The possible Future Enhancements are as discussed below.

Park assists: Once the car has found a suitable parking slot, all that the driver is required to do is to move forward and then bring the vehicle to a standstill. He then has to switch to reverse gear, and just let go of the steering wheel. The system will then take over the wheel and begin to self-maneuver the car using its rear-view camera to adjust the track overlay, which you can observe on the screen which is placed on the car's entertainment console area. The steering wheel during park assist is shown in fig 9.

Fig. 9: Steering wheel during Park assists

Night vision: Driving in the dark is still one of the most strenuous driving situations and one which tends to present a greater risk. A thermal imaging camera covers an area up to 300 m in front of the vehicle is shown in fig 10. The image created on the central monitor displays objects more brilliantly. People (pedestrians at the edge of the road) and animals (wild animals crossing the road) would thus be the brightest areas of the image.

Fig. 10: Camera covers an area up to 300m in front of the vehicle.

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