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An Experiment on Electric Power Steering (EPS) System of a CAR

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Abstract. This paper describes an experiment on Electric Power Steering (EPS) system of a car. Nowadays EPS system can be considered as a Mechatronics system that reduces the amount of steering effort by directly applying the output of an electric motor to the steering system. In this paper, the constitutions, operational mechanism and control strategies of EPS system are introduced. A potentiometer measures driver input to the steering wheel, both direction and rate of turn. This information is fed into a microcontroller that determines the desired control signals to the motor to produce the necessary torque needed to assist. Although an electro hydraulic power assisted steering system can be used to reduce the fuel consumption, but the maximum benefit can be obtained if electronic system is applied instead of the hydraulic mechanism. The paper shows that a good power steering control technique is achieved by designing a Mechatronics system. The experimental results for the designed EPS system are also analyzed in this paper.

Introduction

EPS system has attracted much attention for their advantages. It uses power only when the steering wheel is turned by the driver, it consumes approximately one-twentieth of the energy of a conventional hydraulic power steering systems [4] and, as it does not contain any oil, it does not pollute the environment both when it is produced and discarded. Additionally, the software built into the EPS controller shows a better result in high performance and easy tuning during the experiment of the prototype of EPS system.

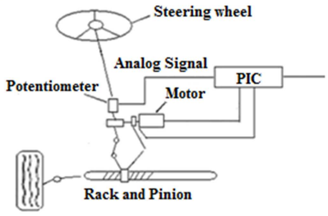


Figure 1. Conceptul diagram of an EPS system.

The main purpose of electric power steering system is, to provide assistance to the driver. This is achieved by using the potentiometer, which measures the steering wheel movement and sends a signal to the controller which is proportional to this movement. The movement information is processed in the controller and an assist command is generated. This command is given to the motor, which provides the torque to the assist mechanism. figure 1 shows a conceptual diagram of an EPS system in which the reduction gear is located directly under the steering wheel.

It is said that power steering was invented in the 1920s by Klara Gailis and George Jessup in Waltham, Massachusetts, USA. However, the earliest known patent related to power steering was filed as recorded by the US Patent Office on Aug. 30, 1932, by Francis W. Davis. There was another inventor, Charles F. Hammond, who was an American, born in Detroit, filed similar patent as recorded by the Canadian Intellectual Property Office on Feb. 16, 1954. Chrysler Corporation introduced the first commercially available power steering system on the 1951 in Chrysler Imperial under the name Hydraguide.

Preliminaries

Power Steering

Power steering is a system for reducing the steering effort by using an external power source to assist in turning the wheels. Conventional power steering systems use an engine accessory belt to drive the pump, providing pressurized fluid that operates a piston in the power steering gear or actuator to assist the driver. In electro-hydraulic steering system, a high efficiency pump is used which is driven by an electric motor. Pump speed is regulated by an electric controller to vary pump pressure and flow, providing steering efforts for different driving situations.

Electronically Controlled Hydraulic Power Steering System

This system consists of a linear solenoid valve, a vehicle speed sensor, and other electronic devices located in part of the circuit of the hydraulic system [3] [4]. The opening of the solenoid valve is controlled based on signals of the vehicle speed sensor. The flow and pressure of the hydraulic fluid is controlled by means of the opening of the solenoid valve. The assist rate is smoothly and continuously varied in response to the vehicle speed, so that when the vehicle is stationary, the opening of the solenoid valve is small to ensure that the steering effort is appropriately light. When the vehicle is moving at high speed, the opening of the solenoid valve is large to ensure that the steering effort is appropriately heavy.

Flow Control Method of the system uses a solenoid valve that is located at the pump discharge port as shown in figure 2. The electronic control device regulates the solenoid valve opening at high vehicle speeds to reduce the pump discharge volume to increase the required steering effort. The flow of hydraulic fluid to the power cylinder is reduced when driving at high speeds, so that the magnitude of the steering response rate and the steering reaction force are balanced at a point of equilibrium.

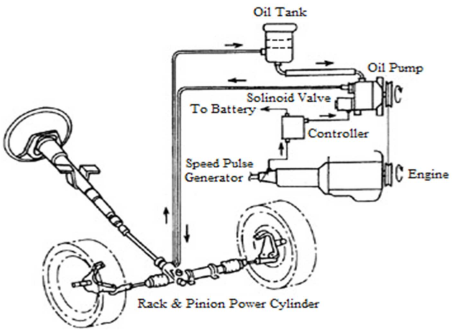


Figure 2. Flow control method of a hydraulic power steering system.

Cylinder Bypass Control Method is another well known method where a solenoid valve and a bypass line are located between both chambers of the power cylinder. Like the flow control method, this system may also seek the equilibrium point for the steering response rate and the steering reaction force.

Hybrid System

Hybrid systems utilize a flow control method in which the hydraulic power steering pump is driven by an electric motor. The steering effort is controlled by controlling the rotational speed of the pump. The drive efficiency of the generator and motor are low compared to that of the hydraulic pump, which is driven by the vehicle engine. Because of the pump is not being driven by the vehicle engine, there is also a large degree of freedom in the selection of the mounting location of the pump.

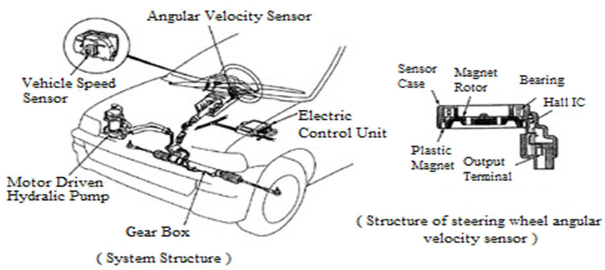


Figure 3. The system of steering wheel speed responsive method.

In *Steering Wheel Speed Responsive Method* the system consists of components such as a vehicle speed sensor, steering wheel angular velocity sensor, an electronic control unit, and a motor-driven hydraulic pump, as shown in figure 3. The pump flow volume is controlled in accordance with the angular velocity of the steering wheel and the vehicle speed.

Electric power steering (EPS)

EPS is replacing hydraulic power steering in many new vehicles today [1]. One of the advantages of electric power steering is that it eliminates the power steering pump. This improves fuel economy while also eliminating the weight and bulk of the power steering pump and hoses. Electric power steering is also quieter than hydraulic systems. EPS can be fine tuned with a precision that is hard to match with hydraulic controls. By monitoring the driver's steering inputs, vehicle speed, and other suspension dynamics, the system can provide just the right amount of steering effort to match rapid changes of the driving conditions.

The EPS system consists of a steering-assist motor on the column with a steering rack at the wheels and 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 the torsion rod with a torque-sensing device. The upper half and the 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. Based on a predefined *"force map"* table, the computer matches the input torque command to generate signals to moves the motor. The quicker the driver turns the wheel, the quicker it will respond, with responds time in milliseconds. This system eliminates the lag and the cavitations that can occur in hydraulic systems.

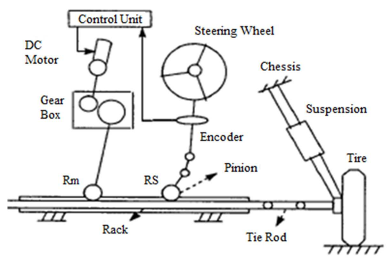


Figure 4. Physical rack type EPS and vehicle systems.

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 motor. The control unit is also designed to protect the motor against voltage surges from a faulty alternator or charging problem.

There are four types of electric power assisted steering systems are presently under development for use with rack and pinion steering systems.

- Column type – The electric motor is mounted on the steering column.
- Pinion type - The electric motor is mounted at the gearbox where the pinion gear contacts the rack.
- Double-pinion-type – this setup has two pinion gears that move the rack. The second rack and pinion located along the rack has the electric motor connected to it to give the power assist.
- Rack-type – the electric motor is connected directly to the rack, sometimes concentric to the rack. To apply its force along the centerline of the rack, it is able to handle larger rack loads.

From a manufacturer's perspective, using electric power steering reduces assembly line time, allows the easy software tuning of the steering assistance characteristics to suit a variety of cars for example a sports car or a limousine, and has a potential to improve reliability as 53% of all power steering warranty.

BMW's active hybrid drive concept is based on an active transmission and ultra capacitor 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. Ultra capacitors provide energy storage and boost performance for the system. With new approaches to rear wheel steering, supplement energy capability from ultra capacitors, and other system improvements in sensing, power and control, EPS should appear on far more vehicles in the future.

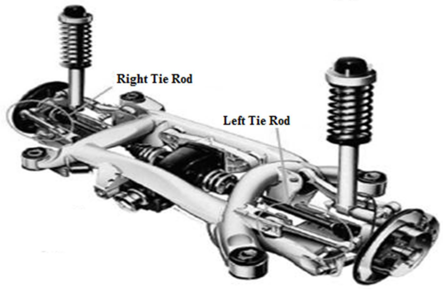


Figure 5. Continental's rear wheel steering system changes the length of the right and left tie rods in the rear of the vehicle to achieve a few degrees of steering.

Selection of Components

In designing and controlling the electric power steering system, it is important to choose the right equipments to accomplish the objectives of the project. The components that were used for the experiment are: Potentiometer, DC Motor, Microcontroller, Rack and pinion mechanism, Steering, Bearing, Spur gears, Wheel, 12V car battery.

Sensor Suite

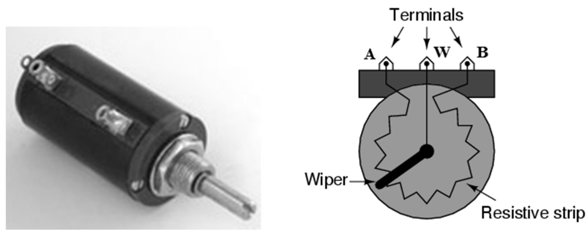
A sensor is a device that responds to a physical stimulus and transmits a resulting response as an electrical signal relating to the quantity being measured. In this experiment a potentiometer (pot) is used as a simple electronic component which is rotary in design. As the turning of the shaft, the internal wiper moves along a resistance track. There are only three terminals A, B and W as shown in the figure 6(b). Between terminals A and B, there should be the actual value of the pot, for example, with a 10 kilo-ohm pot has around 10k resistance. Measuring between W (wiper) and any of the terminals A or B will give a resistance that alters as the adjustment of the rotary shaft of the pot.

Some rotary potentiometers have a spiral resistive strip, and a wiper that moves axially as it rotates, so as to require multiple turns of the shaft to drive the wiper from one end of the potentiometer's range to the other end. Multi-turn potentiometers are used in applications where precise setting is important. The potentiometer can be used as a voltage divider to obtain a manually adjustable output voltage at the slider (wiper) from a fixed input voltage applied across the two ends of the pot. The voltage across R_L can be calculated by:

$$V_L = \frac{R_2 R_L}{R_1 R_L + R_2 R_L + R_1 R_2} \cdot V_s \quad (1)$$

If R_L is large compared to the other resistances like the input to an operational amplifier, the output voltage can be approximated by the simpler equation:

$$V_L = \frac{R_2}{R_1 + R_2} \cdot V_s \quad (2)$$

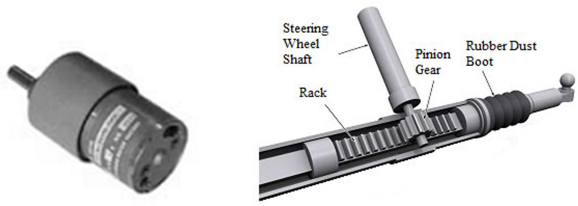


(a) Potentiometer (POT) (b) Rotary POT construction

Figure 6. WXD3-13 wirewound potentiometer (resistance range: 100ohm-56kohm, Tolerance of total resistance: ± 5%, Angle of rotation: 3600± 20°, Voltage rating: 160V, Torque: 3.5-100mNM, Power rating: 3W in 55ºC - 0W in 125ºC).

Motor Selection

A motor is a device that takes electrical energy and converts it into mechanical energy to turn a shaft. A DC motor uses either generated or rectified DC power and it is often used when variable-speed operation is required. The DC motor has a high torque vs. falling speed characteristic and this enables it to deal with high starting torques and to absorb sudden rises in load.



(a) (b)

Figure 7. (a) SPG30-75K DC Geared Motor, (b) Rack and pinion cutaway.

A direct current (DC) motor driven by a DC power source includes a stator of a permanent magnet, fixedly mounted on an outer side of a main body, a rotor rotated by attraction and repulsion with the stator, and a brush for supplying current to a coil in contact with the rotor. The rotor includes an iron core fixedly mounted on a rotary shaft to be rotated, a coil wound on the iron core is to provide the electromagnetic property by means of current applied to the iron core, and a commutator for supplying current to the coil. The actual DC motor is not a loss-less transducer, having resistance at the rotor windings and the commutation mechanism. Windings may exhibit some inductance, which stores energy. In the equivalent circuit of the motor, the relationship between the terminal voltage V_m, the impendence L, the resistance R, the induced voltage constant k, the revolution speed N, the current i and the time t are expressed by the following equation (Ronald K. et al.,1999). It is known that the current i, is proportional to the motor torque T_m.

$$\mathrm{V_m} = \mathrm{L}.\left(\frac{di}{dt}\right) + R.i + k.N \tag{3}$$

Basic steering components

1) Steering ratios and Turning circles: Every vehicle has a steering ratio inherent in the design. Steering ratio gives mechanical advantages to the driver allowing to turn the tyres with the weight of the whole car sitting on them. More importantly, it does not need to turn the steering wheel a ridiculous number of times to get the wheels to move. Steering ratio is the ratio of the number of degrees turned at the steering wheel vs. the number of degrees the front wheels are deflected. For example, if the steering wheel is turned to 20° and the front wheels only turn 1° that gives a steering ratio of 20:1. For most modern cars, the steering ratio is between 12:1 and 20:1. This coupled with the maximum angle of deflection of the wheels gives the *lock to lock* turns for the steering wheel. For example, if a car has a steering ratio of 18:1 and the front wheels have a maximum deflection of 25°, the steering wheel has to turn 25°x18, which is 450°. So the entire steering goes from -25° to +25° giving a *lock to lock* angle at the steering wheel of 900°, or 2.5 turns (900° / 360). For racing cars, the steering ratio is normally much smaller than for passenger cars - i.e. closer to 1:1, as the racing drivers need to get fuller deflection into the steering as quickly as possible.

The turning circle of a car is the diameter of the circle described by the outside wheels when turning on full lock. There is no hard and fast formula to calculate the turning circle. If the Turning Circle Radius is considered as T_r, the equation can be expressed as,

$$T_r = \left(\frac{Track}{2}\right) + \left(\frac{Wheel\ base}{\sin\ (average\ steer\ angle)}\right) \tag{4}$$

2) Rack and pinion: 99% of the car steering systems are made up of the same three or four components. The steering system has a steering wheel that is connected with the steering arm with a pinion that moves the rack left or right along the axis of the front wheel. The tie rods are connected to the ends of the Rack with balls and socket joints. The purpose of the tie rods is to allow suspension movement as well as an element of adjustability in the steering geometry. The tie rod lengths can normally be changed to achieve these different geometries. Rack and pinion steering helps the driver to control the wheels' position precisely. Depending on the location of the electric assist unit, the assistance force can be transmitted to the steering mechanism by a number of means which are,

TABLE I. GEAR METHOD

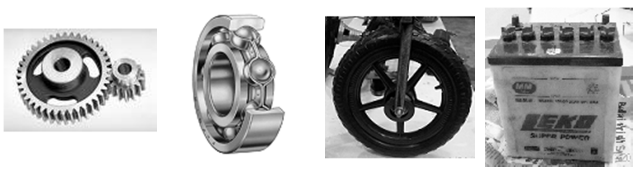
Method	Table Column Head	Method
Pinion assist	Under the dashboard on the steering column	Motor > worm gear > column shaft > pinion shaft
	On the steering rack input pinion	Motor > gear train > pinion shaft
Rack assist	On the steering rack	Motor > ball screw > rack shaft
	On a second pinion on the steering rack	Motor > planetary geartrain > another shaft pinion > rack shaft

There are a couple different types of steering gears. The most common are rack and pinion and circulating ball. The *rack and pinion* gear set does the following two things,

- It converts the rotational motion of the steering wheel into the linear motion needed to turn the wheels.
- It provides a gear reduction, making it easier to turn the wheels.

The figure 7 (b) shows an example rack and pinion system as well as a close-up cutaway of the steering rack itself.

3) Selaction of Gears, Bearings, Wheels and Power Suply: Gears are machine elements used to transmit rotary motion two shafts, normally with a constant ratio. The pinion is the smallest gear and the larger gear is called the gear wheel. Usually gears can change rotational speed, convey rotary motion to a parallel shaft and can also convey rotary motion from one axis to another at any angle. The spur gear is simplest type of gear manufactured and is generally used for transmission of rotary motion between parallel shafts.



(a) Spur gears (b) Ball bearing (c) Wheel (d) 12V car battery

Figure 8. Selection of Gears, Bearing, Power Supply and Wheels.

Bearings reduce friction by providing smooth metal balls or rollers, and a smooth inner and outer metal surface for the balls to roll against. These balls or rollers bear the load, allowing the device to spin smoothly. Ball bearings, as shown in the figure 8 (b), are probably the most common type of bearing. These bearings can handle both radial and thrust loads, and are usually found in applications where the load is relatively small.

In a ball bearing, the load is transmitted from the outer race to the ball and from the ball to the inner race. Since the ball is a sphere, it only contacts the inner and outer race at a very small point, which helps it spin very smoothly. But it also means that there is not very much contact area holding that load, so if the bearing is overloaded, the balls can deform or squish, ruining the bearing.

Tires are ring-shaped parts, either pneumatic or solid including rubber, metals and plastic composites that fit around wheels to protect them and enhance their function. Tires enable better vehicle performance by providing traction and load support. Tires form a flexible cushion between the vehicle and the road, which smooth out shock and makes for a more comfortable ride while keeping the wheel in more constant contact with the road.

A car battery is a type of rechargeable battery that supplies electric energy to an automobile. Automotive starter batteries, usually of lead-acid type, provide a nominal 12-volt potential difference by connecting six galvanic cells in series. Since the cells naturally produce about 2.1 V each, the actual voltage is roughly 12.6 V (2.1 × 6 = 12.6 V) at full charge. Lead-acid batteries are made up of plates of lead and separate plates of lead oxide, which are submerged into an electrolyte solution of about 35% sulfuric acid and 65% water. This causes a chemical reaction that releases electrons, allowing them to flow through conductors to produce electricity. As the battery discharges, the acid of the electrolyte reacts with the materials of the plates, changing their surface to lead sulfate. When the battery is recharged, the chemical reaction is reversed, the lead sulfate reforms into lead oxide and lead.

Controller Selaction

The Microchip's PIC 16F877A, the 40 pin 8-Bit CMOS FLASH Microcontroller is targeted to provide single chip solution to digital motion control. The chip has 8 Kbytes of FLASH programmable memory, 360 byte of data Memory (RAM), 256 byte of EEPROM Data Memory, 33 inputs or out puts pins. The controller may receive analog signal input from up to 8 channels, AN0 to AN7. The controller has two PWM outputs of each module.

Quadruple high current half-h driver, L293D is considered to drive the DC motor. The L293D is designed to provide bidirectional drive currents up to 600-mA at voltages from 4.5V to 36V. DC motor driver techniques are of two types, one is linear application and other is Pulse Width Modulation (PWM) amplifiers, the pulse signal that the width can be varied. The DC motor is controlled by the one unit outputs, PWM1, through the pin C1 of the controller. The other pins C0, D0 are connected with the IN1 IN2 of the driver IC in respective order to control the direction of rotation and movement of the driver motor.

Conceptual Design of the System and Development of the Algorithm

In designing of the controller for the power steering system, a potentiometer is used as the sensor to detect the rotational direction and force. It converts the motion of the steering into a change of resistance, and this change is used to control the DC motor to assist the movement of the Rack and Pinion of the system.

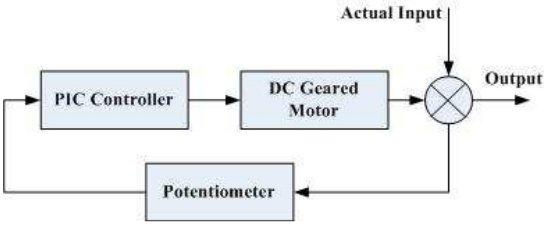


Figure 9. Controller block diagram of EPS system.

The controller block diagram is represented in the figure 9 where the actual input indicates the steering movement. This movement is sensed by the Potentiometer sensor and generates the corresponding analog signals which are converted into digital signals through the ADC channel of the PIC Controller. The controller generates necessary outputs to drive the DC Motor that assist the steering movement, the output of the system. Figure 10 shows the conceptual design of the EPS system for a car.

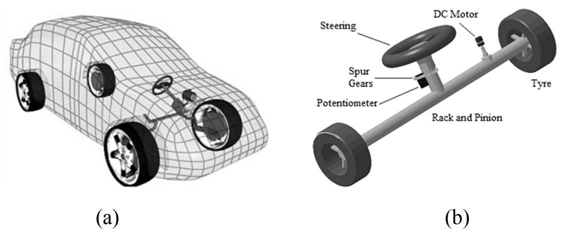


Figure 10. (a) Conceptual design of the EPS system for a car, (b) Basic design of EPS prototype.

Mechanical Design and Algorithm of the EPS system

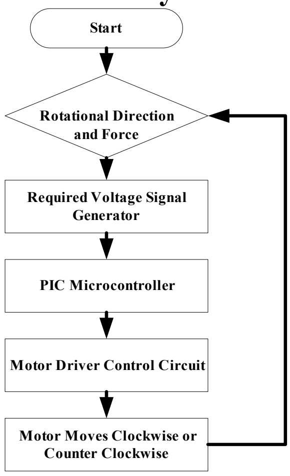


Figure 11. Flow diagram of the designed algorithm for the EPS system.

Figure 10 (b) shows the basic design of the EPS system where the DC Motor is used with the Rack of the steering system. The potentiometer is attached with the steering arm having a Spur Gear in between them. The gear is used to adjust the movement of the sensor shaft so that it can sense the changes of the rotational angles in a precise manner. Figure 11 shows the strata of the logical flow diagram.

Experimental Setup and Testing

The prototype of the Electric Power Steering system is tested to analyze its functionality and performance. In figure 12, the experimental setup of the system is demonstrated. The EPS system having a control unit detects a rotation of a steering column and adjusts power assist for steering according to a signal received from the potentiometer.

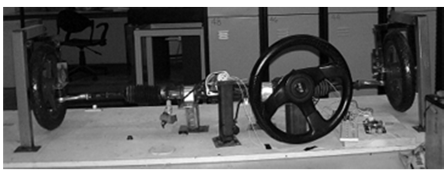


Figure 12. Experimental setup of the Electric Power Steering (EPS) system.

Reading analogue signals of the potentiometer

This experiment is conducted to get the analogue values of the potentiometer for each degree of the rotational change. From the experiment, the value of the initial position of the potentiometer is selected as 127 in decimal format. In order to rotate the wheel as 45°, 45 values are taken both for positive and negative increment that indicate the clockwise and anti-clockwise movement of the potentiometer shaft. The results are tabulated as shown in the Table II.

TABLE II. VALUES OF POTENTIOMETER OUTPUT FOR CHANGING EACH DEGREE FROM INITIAL STATE

Value > 127		Value < 127	
Hexadecimal	*Decimal*	*Hexadecimal*	*Decimal*
0 x AB	171	0 x 7E	126
0 x AA	170	0 x 7D	125
0 x A9	169	0 x 7C	124
Intermediate values		Intermediate values	
0 x 80	128	0 x 52	82

Experimental Results

(a)

(b)

Figure 13. (a) Experimental result of the prototype system after applying a small force to the steering, (b) Experimental result of the left wheel of the EPS system.

The front view of the system shown in the figure 13 says that the EPS system is working and the wheel has been assisted to turn to the right when the driver turns the steering.

A postmortem of the project

Although the model of EPS system can be considered as simpler than any other models studied, a lot of difficulties were faced during the project. First problem was to design the mechanical part of the model that can imitate an actual steering system. Basically the mechanical design was done based on a simple concept. Selecting and finding the materials for the support, shaft, gear and rack and pinion for the EPS mechanical part was a very critical job. For this test project, the waste materials were used to make it easier and cost effective. To fix and synchronization of one part with another, it needed to measure the dimensions of each of the mechanical parts carefully. Designing the algorithm and programming the controller were another important and complex part to make the system effective and robust.

Conclusion

EPS is an electric power steering system that is controlled by an algorithm embedded in a PIC microcontroller. An EPS system occupies less space in the engine compartment. It is also easier to assemble and reduces fuel consumption. It eliminates the need for toxic hydraulic oil in the steering system. There is a great scope to improve the system both in mechanical and control. A rotary encoder can also be used instead of the potentiometer. Rotary encoder is an electro-mechanical device used to convert the angular position of a shaft or axle to an analog or digital code, making it an angle transducer. The system can be improved to operate intelligently by designing an intelligent control system. It is also possible to add another sensor like Infrared Sensor to detect the disturbance on the vehicle moving track, where the wheel will turn automatically to avoid the disturbance. Using Sonar Sensor or Vision Sensor it is possible to make the system as well as the vehicle more intelligent. Automatic parking of a car also can be achieved by designing an intelligent control algorithm for the vehicle where EPS system plays a great role.

Acknowledgment

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References

[1]. Amuliu Bogdan Proca and Ali Keyhani, “Identification of power steering system dynamic models,” Elsevier Science, Mechatronics 8, 1998, pp. 255-270.

[2]. Xin Li, Xue-Ping Zhao and Jie Chen, “Control Design for Electric Power Steering System Using T-S Fuzzy Model Approach,” International Journal of Automation and Computing, May 2009, pp. 198-203. doi: 10.1007/s11633-009-0198-0.

[3]. Zhanfeng Gao, Wenjiang Wu, Jianhua Zheng and Zhanpeng Sun, “Electric Power Steering System on Fuzzy PID Control,” Proc. The Ninth International Conference on Electronic Mesearment and Instruments (ICEMI 2009), IEEE 2009, pp. 456-459.

[4]. Zeng Qun and Huang Juhua, “The Development of Control Unit in Automotive Electric Power Steering System,” Proc. 2009 Asis-Pacific Conference on Information Processing (APCIP 09), IEEE 2009, pp. 242-245, doi: 10.1109/APCIP.2009.68.