

Magneto-Rheological Coupling Based Hydraulic Power Steering: Low-cost Solution for Fuel Economy Improvement

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ABSTRACT

This paper describes a Magneto-Rheological coupling based Hydraulic Power Steering (MRHPS) system developed for improving fuel economy in conventional vehicles. The MRHPS system reduces the parasitic losses associated with the power steering pump and improves fuel economy in full-size trucks (and SUVs) by up to 3%, while maintaining the production hydraulic power steering system performance. The MRHPS is a low cost alternative to electric power steering and electro-hydraulic power steering systems and requires significantly less electric power while resulting in similar fuel economy gains.

With the MR coupling the power steering pump is run at optimum speeds depending on the steering angle, angle rate and vehicle speed, and the pump is run in closed loop speed control mode so that factors like temperature, manufacturing tolerances, aging, etc. will not degrade the steering performance. A fail-safe, fault-management system was also developed that can take remedial action to keep the clutch functioning, when the nature of the fault permits continued operation thereby providing uninterrupted power assist without sacrificing the fuel economy gains. Several prototype clutches were built and installed in full-size trucks and the average improvement in fuel economy was found to be 3% which is quite significant. The prototype clutches also met the prescribed durability and high speed tests.

INTRODUCTION

The power assist steering in a conventional vehicle uses a hydraulic system that employs an engine driven hydraulic pump for generating pressurized fluid that is coupled to the hydraulic steering gear of the vehicle. Since the pump is driven directly by the engine using a belt, it operates continuously as long as the engine is

running; resulting in continuous losses due to constant circulation of the hydraulic fluid through the steering gear. Also, the pump has to be designed to provide the required flow and pressure for the worst case engine speed which could be near idle, under static steer conditions. This results in much higher pump flow at higher engine speeds further increasing the losses in the hydraulic system resulting in increased fuel consumption. This system also suffers from the disadvantage that there is no control of steering effort as a function of vehicle speed. Generally, these systems have higher power assist at high vehicle speeds that makes the steering feel loose. However, a tight steering feel at high speeds is preferred to get a better feel of the road. There were several systems like Magnesteer [1] proposed in the past for achieving this vehicle speed dependent steering effort but they do not address the parasitic pump losses that worsen the fuel economy.

More recently, electro hydraulic power steering systems [2], [3] have been used to provide an on-demand hydraulic pressure using an electric motor to drive the hydraulic power steering pump. A variable speed motor drive typically employing brushless dc motor drive is used in such systems to run the pump. There are two main issues associated with such systems. The electro hydraulic power steering requires the motor and the controller that add to the cost of the overall steering system. Also since an additional control element is added to the system, the speed of response of the overall system is limited.

Electric Power Steering (EPS) system employed in certain production vehicles is another option to provide on-demand power steering assist to improve fuel economy. However the application of EPS systems is limited to passenger cars and small size SUVs due to the limited electric power available to drive these actuators.

Another way of achieving on-demand assist is to use magneto-rheological (MR) fluid coupling (or clutch) integrated between the accessory drive and the hydraulic power steering pump [4], [5], to provide a means to directly control the speed of the hydraulic pump driven by the engine. The magneto-rheological fluid coupling (or clutch) provides a continuously adjustable speed by controlling the torque transmitted from the drive shaft to the power steering pump. The main advantage of using such a system is that the modifications required on the vehicle to achieve on-demand assist are minimal. Since the basic hydraulic power steering system is still used, it is possible to achieve production steering feel through controller tuning while improving the fuel economy.

MRHPS SYSTEM FUNCTIONALITY

In the conventional hydraulic power steering system, the shaft of the hydraulic pump is coupled directly to the engine through a belt-pulley arrangement and pump follows the engine speed. In the MRHPS system, the MR coupling is used between the power steering pulley and the pump. The MRHPS power steering pump assembly is shown in Fig.1. The pulley driven by the engine through the belt in the conventional hydraulic steering system forms the input shaft (outer rotor) for the MRHPS system. The input shaft (from the pulley) is coupled to the output shaft (pump shaft) through the MR coupling. Between the inner (output) and outer (input) shaft is a dual air gap arrangement which is filled with the MR fluid. The MR coupling also has a stationary coil with a support bracket to the pump housing to generate magnetic flux. By adjusting the current flowing through the coil, it is possible to vary the pump speed from a minimum

to a maximum. The minimum speed corresponds to the drag torque in the clutch and the maximum speed corresponds to the input shaft speed (engine follow mode).

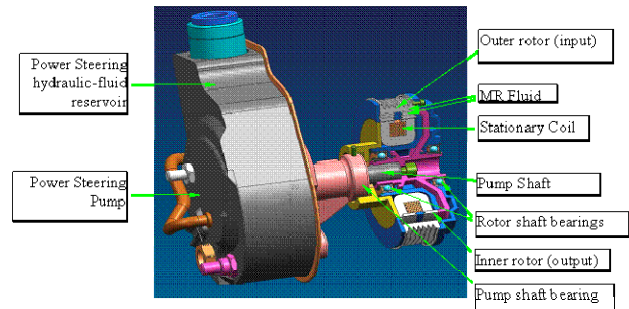


Fig.1. MRHPS power steering pump assembly

The MR coupling transmits the torque from the input shaft to the output shaft needed to run the power steering pump at the desired operating speed. Since the input and output shafts run at different speeds depending on the amount of coupling, the slip power generates heat loss in the coupling. The housing used for the MR coupling is designed to dissipate the heat generated within the coupling and keep the temperature within limits.

MRHPS CONTORLLER DEVELOPMENT

BASIC CONTROL PHILOSOPHY

In the conventional hydraulic power steering system where the power steering pump speed follows the engine speed as shown by the curve A in Fig.2. The basic control philosophy of the MRHPS controller is to run the pump at optimum speed under any given operating condition instead of following the engine speed. The optimum speed is chosen such that the resulting hydraulic pressure is sufficient to provide comfortable level of power steering assist. When the steering angle and angle rate are zero, the steering assist required is minimum and the pump runs at minimum possible speed. When the steering wheel is turned in either direction from the on-center position, the amount of assist torque required increases and the pump speed is increased accordingly to produce sufficient hydraulic pressure to provide the required steering assist. Typical pump speed variation with engine speed is shown by curve B in Fig.2.

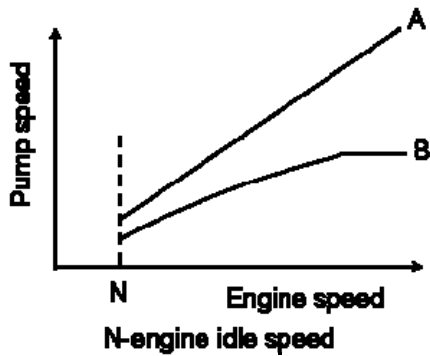


Fig.2. Variation of pump speed with and without MR coupling

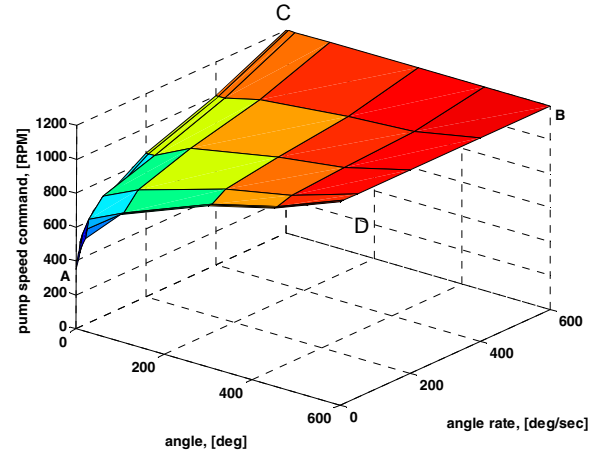


Fig.5. Typical two-dimensional lookup table

PUMP SPEED COMMAND GENERATION

For generating the pump speed command, the controller uses the steering angle and angle rate information. The block diagram of the electronic controller for the MRHPS pump coupling is shown in Fig. 4. It receives the steering angle, angle rate, vehicle speed, engine speed and brake signal information from the vehicle CAN communication bus. The pump speed command is generated as a function of steering wheel angle, angle rate and vehicle velocity using a two-dimensional lookup table [6]. A typical two-dimensional lookup table function is graphically shown in Fig. 5.

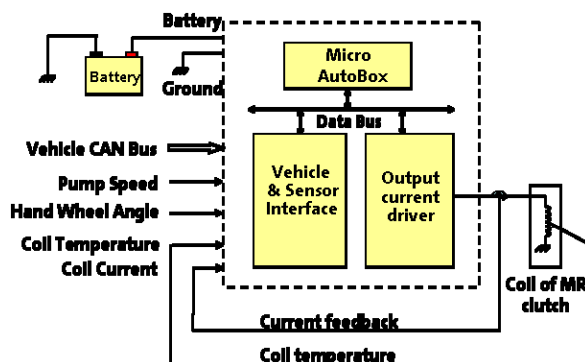


Fig.4. Block diagram of the MRHPS controller

For vehicle speeds less than a chosen threshold, the initial value of pump speed command is set to 350 RPM corresponding to Point A in Fig.5, when the steering wheel is in the on-center position (with zero steering wheel angle and angle rate). The pump speed command is ramped up from this value with increase in either the steering wheel angle or the angle rate as shown in Fig.5. The maximum pump speed command in the lookup table is chosen to correspond to that value beyond which the internal flow by-pass valve gets activated. At higher values of steering angle and angle rate, the pump speed command is set to the maximum value as shown by lines BC and BD in Fig.5.

At vehicle speeds above the threshold, a second two-dimensional lookup table is used in which the minimum pump speed is set to 400 RPM. The maximum pump speed command is still maintained at the same level as the previous case. The pump speed command values at other operating points are correspondingly increased.

VEHICLE SPEED DEPENDENT VARIABLE EFFORT STEERING

For better steering performance, several two-dimensional look-up tables can be used instead of using only two tables [6]. The vehicle speed from zero to maximum can be divided into several speed ranges and for each range, one two-dimensional table can be used. The minimum value for the pump speed command can be increased in steps as the vehicle speed increases. This method gives additional flexibility in fine tuning of the steering performance to the desired level.