電子輔助轉向系統
控制策略調校之試驗平台開發

論文

IA-96-0035

委託單位：經濟部技術處
執行單位：財團法人車輛研究測試中心
計畫主持人：廖慶秋
撰　寫　人：葉智榮
執行部門：研發處 底盤系統發展專案
執行期間：96.1.1～96.12.31

中華民國九十六年八月一日

VPPC 2007

2007 IEEE Vehicle Power and Propulsion Conference

September 9 – 12, 2007

Wyndham Hotel, DFW South
Arlington, Texas, USA

Conference website
www.vppc07.com

Technical Co-sponsoring IEEE Societies:

Technical Session 12: Dynamic Analysis of vehicular components
Session Chair: Dr. Rochdi Trigui
INRETS, France

Sep 12th, 2007
8:00 am – 9:00 am
Venue: WIMBLEDON ROOM

TS12-1. Development of a Test Bench for Electric Power Steering Control Method Tuning and Validation
Chih-Jung Yeh, Sonic Ho, Micky Lin and Tsung-Hsien Hu; *Automotive Research and Testing Center, Taiwan.*

TS12-2. Modeling, Simulation and Evaluation of a Cooler Model in Modelica using Dymola
Dragan Simic, Anton Haumer, Thomas Baeuml and Franz Pirker; *Arsenal Research, Austria.*

TS12-3. Comparative Analysis of Control Techniques for Efficiency Improvement in Electric Vehicles
Abdelhakim Haddoun, Mohamed El Hachemi Benbouzid, Demba Diallo[1], Rachid Abdessemed[2], and Jamal Ghouili[3]; *University of Western Brittany, France; University of Batna, Algeria; [2]University of Paris, France; [3]University of Moncton, Canada.*

Post-break session
10:30 am – 12:00 pm

TS12-4. Modeling of Non-Salient PM Synchronous Machines under Stator Winding Inter-turn Fault Condition: Dynamic Model - FEM Model
Babak Vaseghi, Babak Nahid-Mobarakeh, Noureddine Takorabet and Farid Meiboy-Tabar; *GREEN, France.*

TS12-5. Study on the Dynamic Characteristics of Pneumatic ABS Solenoid Valve for Commercial Vehicle

九十六年度 科專 計畫技術文件成果摘要表

計畫名稱	車輛底盤次系統關鍵技術開發三年計畫(1/3)	委託單位	經濟部技術處
計畫編號	96-EC-17-A-16-R7-0792	計畫年度	96年度
執行計畫單位	財團法人車輛研究測試中心	執行期間	96.1.1～96.12.31
計畫主持人	廖慶秋	協同主持人	
分項計畫主持人			
技術文件名稱	中文：電子輔助轉向系統控制策略調校之試驗平台開發		
	英文：Development of a Test Bench for Tuning and Validating Electric Power Steering Control Method		
技術文件編號	IA-96-0035		
撰寫人	葉智榮、何世榮、林明志、胡聰賢、許駮譁	撰寫語言	□中文 ■英文 □其他
撰寫日期	96.08.01	頁　數	5頁
報告性質	■論文 □技術報告 □調查報告 □訓練報告 其他______		
論文發表說明	論文性質：□期刊 ■研討會 □其他		
	發表刊物名稱：2007 IEEE VPPC Conference		
	發表國家：美國		
	發表日期：96.09.12		
關鍵詞(中英文)	電子輔助轉向(electric power steering, EPS)		
	試驗平台(test bench)		
	力回饋裝置(force feedback device)		
機密等級	■一般級 □限閱級 □機密級(五年) □極機密級(七年)	解密方式	□自動解密 □提報檢討解密 □不解密

內容摘要

In this study, a test bench for electric power steering (EPS) system has been developed through the integration of the EPS mechanism, steering wheel angle sensor, vehicle speed meter, and the force feedback device. The feedback force can be instantaneously calculated according to the steering wheel angle and the vehicle speed, and then controlled by using two load cells at the ends of the rack as feedback signals. The force feedback device can simulate the reaction force of the rack while the driver turning the steering wheel. Moreover, as the torque sensor and EPS motor signals connect with the data recorder, the test bench can also be used to carry out the EPS performance tests, such as the assistant torque characteristics and the return-to-center performance. Hence, the test bench built in this work can provide engineers with the faster and safer access to the optimization of EPS control methods at the development stage.

Development of a Test Bench for Tuning and Validating Electric Power Steering Control Method

Chih-Jung Yeh, Shih-Rung Ho, Ming-Chih Lin, Tsung-Hsien Hu and Tsung-Hua Hsu
Automotive Research and Testing Center (ARTC)
No.6, LunKung.S.7Rd, Lu-Kang Town,
Changhwa Hsien 505, Taiwan, R.O.C

***Abstract*-In this study, a test bench for electric power steering (EPS) system has been developed through the integration of the EPS mechanism, steering wheel angle sensor, vehicle speed meter, and the force feedback device. The feedback force can be instantaneously calculated according to the steering wheel angle and the vehicle speed, and then controlled by using two load cells at the ends of the rack as feedback signals. The force feedback device can simulate the reaction force of the rack while the driver turning the steering wheel. Moreover, as the torque sensor and EPS motor signals connect with the data recorder, the test bench can also be used to carry out the EPS performance tests, such as the assistant torque characteristics and the return-to-center performance. Hence, the test bench built in this work can provide engineers with the faster and safer access to the optimization of EPS control methods at the development stage.**

I. INTRODUCTION

A steering system rotates the front wheel plane in the desired direction set by the driver's steering input. When the front wheels are steered, righting moments that tend to return the wheels to the original position arise. Although the righting moments provide steering stability, the driver must provide sufficient torque to overcome the moments to steer the vehicle. The considerable steering effort is required for larger vehicles. Power steering systems, therefore, are popular in modern vehicles. Electric power steering (EPS) is a power steering system directly assisted by an electric motor. EPS systems have many advantages over traditional hydraulic power steering systems especially in the engine efficiency, space efficiency and environmental compatibility. An EPS system has the following two functions. First, it can reduce the steering torque and provide various steering feel. Second, the EPS system can improve return-to-center performance of a steering wheel when it is steered. These functions are realized by electrically controlling the assist motor. During the development of EPS control systems, it is helpful to test and tune the control algorithm in the bench circumstances. The bench testing will effectively shorten the time of vehicle tests, and it is safer to find the failure of the control system on the test bench. The main function of the test bench is to simulate the righting moments, which a driver experiences when turning the steering wheel. The righting moments are from the forces occurring between the tire and the road. One of the three forces (the vertical force, the lateral force, or the longitudinal force) acting on the center of the tire contact has a lever to generate the moment [1]. The moment from the vertical force is due to the kingpin offset, the kingpin inclination angle and the caster angle. The force lever of the moment from the lateral force consists of the mechanical trail (from the caster angle) and the pneumatic trail (from the compliance of the tire). Because the lateral force increases while the vehicle speeds up, the righting moment will vary with the speed. The longitudinal force will also contribute to the righting moment when the left and right front loads are different. In general, the EPS test bench use springs for the steering load setting [2][3][4]. The load cannot be automatically adjusted with the change of the vehicle speed. Hence, it is difficult to check the EPS basic control algorithm. For this reason, the tests that could be performed on this test bench will be limited. The purpose of this study is to develop a steering hardware-in-the-loop (HIL) test bench, which has the force feedback devices providing the controlled reaction force at the steering rack. It is helpful for the more accurate bench testing and faster feedback to the EPS control algorithm development.

II. DEVELOPMENT APPROACH

Fig. 1 shows the architecture of the developed test bench for an EPS system. The EPS system shown in Fig. 1 adopts a so-called column-type EPS system in which the assist motor connected to the steering shaft through worm gears delivers the assist torque to the shaft. The force feedback motors attached to the steering system gear by the rack and pinion mechanism apply the reaction forces to the left and right sides of the steering gear.

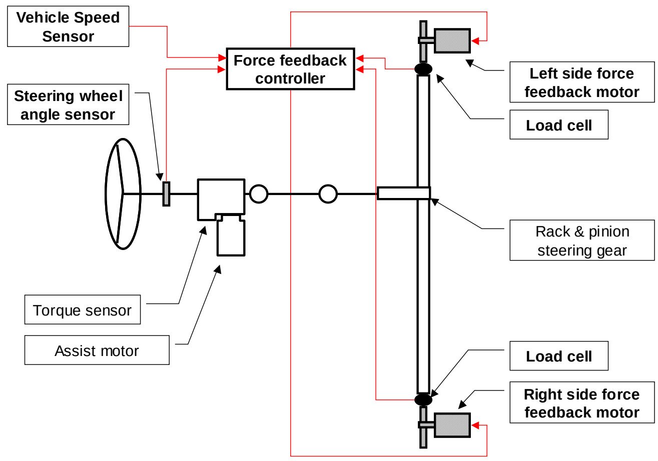

Fig. 1. Simplified schematic diagram of the test bench.

The load cells are installed between the steering system and the force feedback devices, and the steering wheel angle sensor is installed on the steering shaft as shown in Fig. 1. The load cells measure the force applied to the steering rack, and the steering angle sensor measures the driver's input angle. The speed sensor is an analog voltage signal to simulate the longitudinal vehicle speed.

Force Feedback Control

The block diagram of the force feedback device is shown in Fig. 2. The primary goal for controlling the force feedback motor is to keep the load cell tracking the reference reaction force. The reference reaction force is computed via the predetermined map from the vehicle model or the vehicle testing. In this study, a virtual model of a medium passenger car in ADAMS/Car has been used to calculate the left and right side rack force. The rack forces of the both sides under the 180-degree ramp steer with different vehicle speeds on a dry asphalt road are shown in Fig. 3 and Fig. 4. The results are transferred to a look-up table with data, which is dependent on the steering angle and the speed.

The brushless DC motors are used as the force feedback motors. The reference current of the reaction torque is given to the brushless DC motor. However, a difference between the actual and target rack force appears owing to the friction in the transmission mechanism of the force feedback device, when the target rack force is low. As shown in Fig. 2, the force feedback device is closed loop force controlled by the controller so that the friction can be eliminated. From these methods, this test bench can generate the rack force similar to that in the actual vehicle.

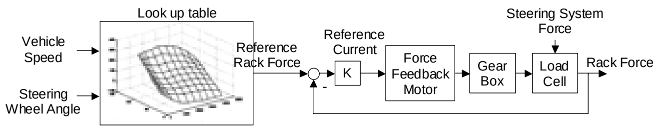

Fig. 2. Block diagram of the force feedback control system.

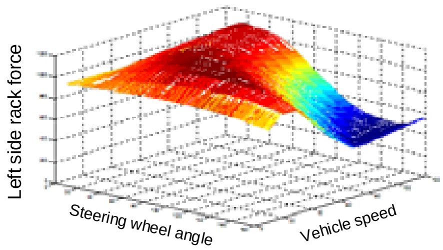

Fig. 3. Left side rack force vs. steering wheel angle and vehicle speed.

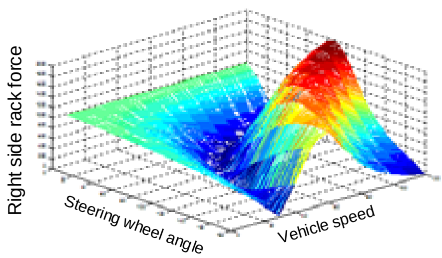

Fig. 4. Right side rack force vs. steering wheel angle and vehicle speed.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The developed test bench is shown in Fig. 5. The reduction ratio of the motor gearbox is 25, and the stroke ratio of the force feedback transmission mechanism is 32 mm/rev. The maximum output torque of the brushless DC motor is 2.36 Nm. The measurement range of the load cell is +/- 10kN.

The examples of the look-up tables for the target rack force are shown in Fig. 6 and Fig. 7. The vehicle speed is set at 10, 40 and 70 km/h. The figures only show the left turn situation.

Fig. 5. The developed test bench.

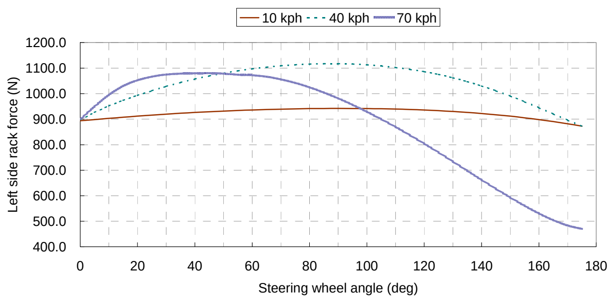

Fig. 6. Example of the left side target rack force.

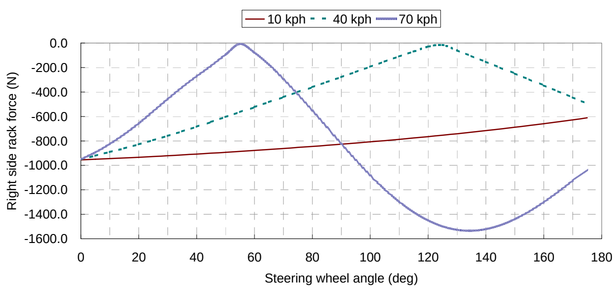

Fig. 7. Example of the right side target rack force.

Force Feedback Control Result

The following figures show the sensors used in the force feedback control system. Fig. 8 is the steering wheel angle sensor installed on the pinion shaft due to the tight space near the steering wheel. This sensor could be omitted if the steering system has a built-in angle sensor. The load cell was installed between the force feedback mechanism and the tie rod as shown in Fig. 9. The microprocessor was used as the controller that receives the CAN and digital signals and then outputs the command signals to the brushless DC motor driver as shown in Fig. 9. Fig. 10 shows the step response of the force feedback control system under the load on the steering wheel. It is observed that the load cell step response is well behaved under the PI feedback control. The load cell and steering wheel angle measured in the test bench was compared with the target rack force at the different vehicle speeds as shown in Fig. 11, Fig. 12 and Fig. 13. The results show the force feedback device can simulate the rack force with the change of steering angles.

Fig. 8. Steering wheel angle sensor for the force feedback control system.

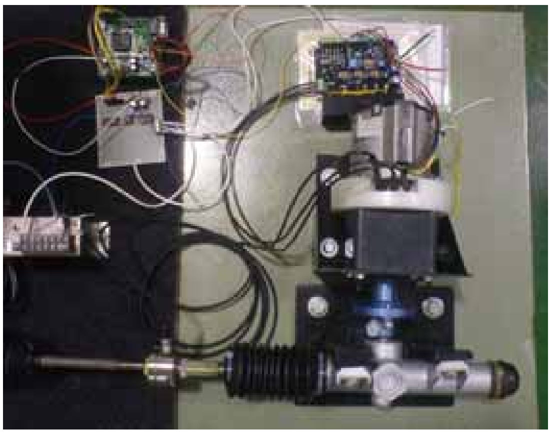

Fig. 9. The load cell, microprocessor and brushless DC motor driver.

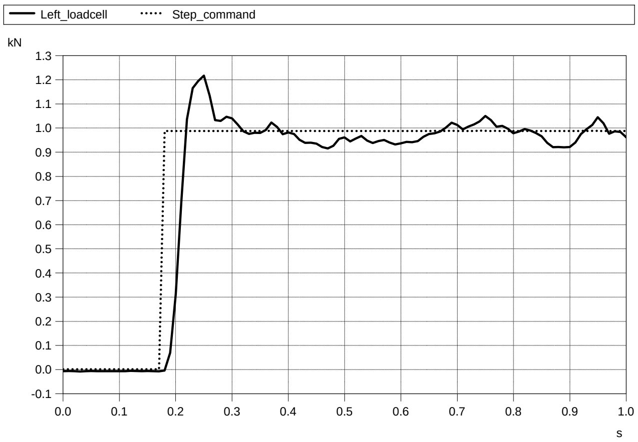

Fig. 10. Step response of the force feedback control system to the target force.

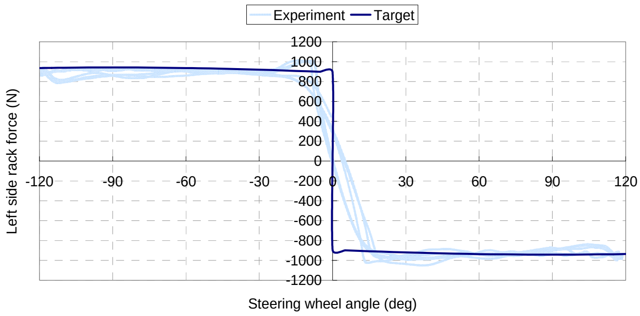

Fig. 11. Comparison of the target and controlled force at 10 km/h.

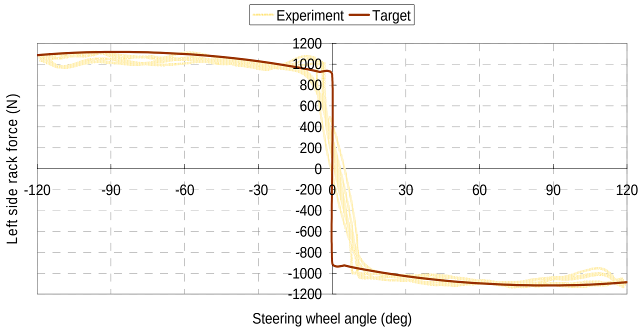

Fig. 12. Comparison of the target and controlled rack force at 40 km/h.

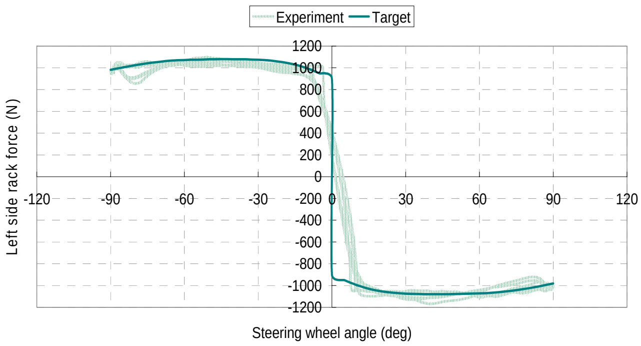

Fig. 13. Comparison of the target and controlled rack force at 70 km/h.

Steering Feel Simulation

The steering wheel torque that the driver feels can be evaluated by using the test bench. The continuous sine steer input is often used to quantify various parameters of the steering performance [5]. The figure of steering torque against steering wheel angle, which is considered to indicate steering feeling, is applied to evaluate steering torque. For this experiment, the column-type EPS system was set up with a steering wheel sensor to enable steering wheel torque and angle to be measured as shown in Fig. 14. The bench testing results without the EPS system assistance are shown in Fig. 15. In each test, the vehicle speed is set at 40 and 70 km/h, and the steering input is a continuous sine wave. From these results, the hysteresis of steering torque around the neutral position of the steering wheel can be simulated using this test bench, and the control method of the EPS system has significant effect on this characteristic. The developed test bench, therefore, can carry out the evaluation of the steering feel.

Fig. 14. Steering wheel sensor for measuring steering torque and angle.

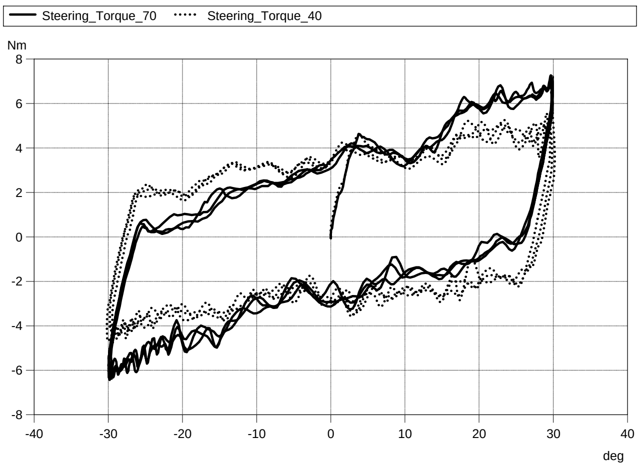

Fig. 15. Steering torque with respect to steering angle at 40 and 70 km/h

EPS Function Tests

Performing tests with EPS power on and off makes it possible to tune the control method. The load cell signals of the test bench can help to check how much torque the EPS motor assists. The test bench can also perform the return-to-center test that is one of the EPS function. The steering wheel is turned at specified angle and then released. It returns to the center by means of the force feedback device. The return rate of the steering wheel can be adjusted through the control method. Moreover, because of the active force feedback device, the developed test bench can simulate the unwanted steer such as the pull and drift behavior. The pull behavior is defined as an unacceptable steering wheel torque that is needed to drive straight. The drift behavior occurs when the hands are taken off the steering wheel and the vehicle leaves the straight line too fast. The driver might complain about the behavior. However, the EPS system has the opportunity to correct it, and the test bench can help to develop the control algorithm.

In addition to the column-type EPS system, the developed test bench is also suitable for all other type EPS systems, because the whole steering system can be installed in the test bench. It can also be used for confirming the steering model. Further investigation is necessary for the test bench to evaluate the steering system in the case of rapid steering action in the future.

IV. Summary

This research has developed a test bench with active force feedback applicable to different types of EPS systems. The developed HIL system is capable of providing the steering column with a load torque computed based on the driving conditions. The driver can feel reaction torque as much as on an actual vehicle. Steering characteristics such as the relationship between the steering wheel angle and the steering torque were reproduced in the laboratory. This test bench can make tuning the EPS control method much more complete and give a safer experimental environment. Therefore, it could significantly reduce the time and cost of vehicle tests. In the future, it can improve simulation accuracy to combine the real time vehicle model with the test bench.

Acknowledgment

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[3] Masahiko Kurishige, Shunichi Wada, Takayuki Kifuku, Noriyuki Inoue, Ryoji Nishiyama and Shigeki Otagaki, "A New EPS Control Strategy to Improve Steering Wheel Returnability," SAE Paper, No. 2000-01-0815, Society of Automotive Engineers, Warrendale, PA, 2000.
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