A steering control simulation system for vehicle simulator

Tang Fang1*, Li PeiXin2

1 Wuhan Second Ship Design and Research Institute, Wuhan, Hubei, 430205, China
2 Hainan University, Haikou, Hainan, 570228, China
*Corresponding author’s e-mail: tangfang008@163.com

Abstract: In order to study man-machine engineering problem with vehicle simulator, a steering control simulation system was designed. The mechanical structure and working process of this system was illustrated. The system model was build, according to low frequency working condition, parameter identification experiment was made to obtain amplitude ratio and phase lag in different frequency. Least square method was used to fit transfer function and frequency response was analyzed. Aligning and steering experiment was set to test this system. The result indicates that steering wheel aligns to zero position in 1 s without oscillation, aligning performance is good and meets the needs of vehicle simulator, torque measured by this system and simulated from transfer function shows great consistency, the transfer function can be applied to control this system. Setting different resistance torque can make research on driver comfort and vehicle handling stability, besides provide some help for power steering, steer-by-wire system design.

1. Introduction

Recent year, studying man-machine engineering problem, optimizing vehicle performance and training drivers by vehicle simulator has become an important method[3, 4], for example, ADSL of Jilin university[3, 4] and NADS of IOWA university[5]. Vehicle simulator is a man in loop system that can’t be carried out by bench test[6, 7], different resistance torque is added to steering wheel to make experiment for driver, which makes effect on driving feeling, comfort and vehicle operating stability[8,9]. Experiment data is studied to research vehicle man-machine engineering problem. In this paper, a steering control simulation system is designed, the system model is established, parameter identification experiment is made to obtain system transfer function, frequency response is analyzed, aligning and steering experiment and Simulink simulation is set to verify system feasiblity.

2. Steering control simulation system

Steering control simulation system includes steering wheel assembly(SWA) and control system. SWA is made up of steering wheel, torque sensor, photoelectricity coder, reducer, direct current(DC) motor and other connect parts, system construction is shown in Fig.1. Control system includes industrial personal computer(IPC) and data collection card. SWA is installed in simulator cockpit to provide steering control for driver, control system is located in console room.
While simulator is running, the driver turns steering wheel according to the visual road in simulator, IPC collects data like torque, steering speed and steering angel, which is send to vehicle dynamics model to calculate vehicle state parameters. The steering wheel resistance torque for driver is counted with different strategies and generated by DC motor, which cause imperceptible feeling of driver’s comfortability and vehicle operating stability. The working process is shown in Fig.2.

3. SWA system model

In order to control the torque output by DC motor, SWA system model must be built. SWA system model includes DC motor system and connection system(SWA except DC motor). Current closed loop block diagram of DC motor system is shown in Fig.3. While, $u_i$ is input current, $W_{ACR}$ is torque controller, $k_s$ is thyristor magnifying modulus, $T_i$ is thyristor average maladjustment time, $R$ is total armature resistance, $T_1$ is electromagnetism time constant of armature loop, $I$ is armature current, $\beta$ is feedback modulus of current, $C_m$ is ratio of electromagnetism torque and current, $J$ and $D$ is SWA system moment of inertia and rotation damp modulus, $C_e$ is reverse electromotive force modulus, $T_m$ is armature output torque, $T_l$ is disturb torque of motor(torque input by driver ), $T$ is DC motor system output torque. The DC motor system transfer function $G(s)$ is:

$$G(s) = \frac{T_m}{u_i} = \frac{\pi C_m K_s W_{ACR} (Js + D)}{\pi\beta K_s W_{ACR} (Js + D) + (T_i s + 1)[\pi R(T_i s + 1)(Js + D) + 30C_e C_m]}$$

![Fig. 3. Current close loop block diagram of DC motor](image-url)
Fig.4 Block diagram of connection system

Connection system block diagram is shown in Fig.4. While, $\theta_m$ is motor axis angel, $\theta_h$ is steering wheel angel, $C$ is torque sensor turn stiffness. Connection system output torque $T_l$ in steering wheel is:

$$T_l(s) = \frac{C}{Js^2 + Ds + C} T_m(s) + \frac{Cs(Js + D)}{s(Js + D) + C} \theta_h(s)$$

4. SWA parameter identification

Build SWA model by block diagram is complicated and uncertain. In this paper, system parameter identification[11] experiment is taken to build SWA model. DC motor of SWA works in low speed and low frequency in the most of time, so the experiment is focus on motor torque, motor rotate speed is not concerned. The main axis of SWA is fixed during experiment, according to SWA most working frequency, input $u_i$ is a series sine wave with frequency of 0.05Hz, 0.1Hz, 0.2Hz, 0.4Hz, 0.5Hz, 0.7Hz, 0.8Hz, 1.0Hz, 2.0Hz, output data $T_l$ is measured, as is shown like Fig.5. Input and output data is taken the Fourier transform, the ratio of amplitude and phase lag is shown Table.1.

![Experiment result of parameter identification](image)

Fig.5 Experiment result of parameter identification

| $f$ (Hz) | $T_l/u_i$ | $\phi$ (s) |
|---------|-----------|-----------|
| 2       | 2.05      | 0.17      |
| 1       | 2.15      | 0.11      |
| 0.8     | 1.9       | 0.07      |
| 0.7     | 1.85      | 0.08      |
| 0.5     | 1.9       | 0.08      |
| 0.4     | 1.8       | 0.15      |
| 0.2     | 1.65      | 0.15      |
| 0.1     | 1.85      | 0.15      |
| 0.05    | 1.8       | 0.3       |
The main purpose of current closed loop is well following features and small overshoot, the higher-order effects can be ignored, according to ratio of amplitude and phase lag, the least square method is used to identify the DC motor system as a second order system, whose transform function $G'(s)$ is:

$$G'(s) = \frac{1}{0.003824s^2 + 0.03868s + 0.5693}$$

The comparison of $G'(s)$ bode diagram and experiment data in different frequency is shown in Fig.6. Fig.6a) is amplitude-frequency characteristic diagram, fig.6b) is phase frequency characteristic diagram. The experiment data points are basically distributed on the bode diagram, frequency characteristic is in good agreement with data points. Because of the torsional stiffness of connection system $C$ is large enough, and SWA system working condition is low frequency, parameter identification is not used with connection system.

5. Performance test verification

5.1 Self-alignment test

Good self-alignment performance is the basic requirement of steering control simulation system, which requires the steering wheel is turned at an angel and suddenly let go, the steering wheel can go back to zero position with short response time and no oscillations. Fig.7 is self-alignment curve of SWA after turning 90°, while $\theta$ is steering wheel angel, $t$ is time. The result shows that the steering wheel is back to zero position in about 1 second without any shocks, this system has good self-alignment which can be used in vehicle simulator.

5.2 Operation test

In vehicle simulator operation test, a relationship between $u_i$ and $\theta$ is preset. The driver turns steering wheel at different angel to feel resistance torque generated by DC motor, output torque $T_l$ measured by torque sensor is shown with dash line in Fig.8. The same $u_i$ is input to transform function $G'(s)$ in simulink, output torque $T'_l$ is shown with solid line in Fig.7.

With comparison of operation test and Simulink, for the same input $u_i$, actual torque $T_l$ measured by steering control simulation system makes a great agreement with $G'(s)$ simulated torque $T'_l$. Therefore, $G'(s)$ can be used as SWA transform function to provide variable torque for drivers in vehicle simulator.
6. Conclusion

(1) In this paper, a steering control simulation system is designed based on vehicle simulator, parameter identification experiment is made to obtain the system transform function $G'(s)$, actual experiment and simulation is made. The result shows that the steering control simulation system has great self-alignment speed without any shocks, $G'(s)$ can be used as SWA transform function to provide variable torque for drivers in vehicle simulator.

(2) Vehicle man-machine engineering problem can be studied with this steering control simulation system, setting different resistance torque strategy can make research on driver comfort and vehicle handling stability. Steering control simulation system can provide some help for steer-by-wire and power assisted steering.

(3) To improve the accuracy of $G'(s)$, the connection system transfer function can be identified separately, more frequency points can be selected for fitting in parameter identification test.

References

[1] Hirata T, Yai T, Takagawa T. Development of the Driving Simulation System MOVIC-T4 and Its Validation Using Field Driving Data[J]. Tsinghua Science and Technology. 2007, 12(2): 141-150.

[2] Shiiba T, Suda Y. Evaluation of driver’s behavior with multibody-based driving simulator[J]. Multibody Syst Dyn. 2007(17): 195-208.

[3] Zhao Y.Q, Gun X, Guo K.H. Development driving simulator[J]. Journal of Highway and Transportation Research and Development. 1995, 12(03): 64-66.

[4] Zong C F, Mai L, Wang D.P, Li Y.J. Study on Steering Effort Preference of Drivers Based on Driving Simulator[J]. Chinese Mechanical Engineering. 2007(8): 1001-1005.

[5] Heydinger G J, Salaani M K, Garrott W R, et al. Vehicle dynamics modelling for the National Advanced Driving Simulator[J]. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. 2002, 216(D4): 307-318.

[6] Pastorino R, Naya M A, Perez J A, et al. Geared PM coreless motor modelling for driver's force feedback in steer-by-wire systems[J]. MECHATRONICS. 2011, 21(6): 1043-1054.

[7] Luo S, Shang G.G, Su Q.Z. A Research on Steering Wheel Force Feedback Control Model for Steering by Wire System[J]. Automotive Engineering. 2006, 28(10): 914-917.

[8] Tang F, Study on Several Key Technologies of Steering operation System in Vehicle Simulator[D]. Zhejiang university. 2013.

[9] Tang F, Wei Y D, Zhou X.J, et al. Research on vehicle dynamics simulation for driving simulator[J]. Advanced Materials Research. 2011, 308-310: 1946-1950.

[10] Yang G, Luo Y. Motor and motion control system[M]. Tsinghua University Press. 2006: 358.

[11] Li Y J, Zhang K. System Identification Theory and Application[M]. National Defence Industry Press, 2004: 240.