Testing and analysis of automotive gearshift performance based on gear shift analysis

Wenquan Shen¹ | Qiugui Zhang¹ | Zhenwen Chen² | Wei Mao² | Yongxiang Li²

¹Zhejiang Wanliyang Co. Ltd, Jinhua, China
²Xingzhi College, Zhejiang Normal University, Jinhua, China

Abstract
With the increasing demand for vehicle handling comfort in the market, the development of gear shifting performance test systems for automobile transmission has become one of the keys to improving the competitiveness of automobile products. In order to continuously improve the shifting quality of the automobile gearshift control, this research focuses on the study of shifting quality, uses GSA (gearshift analysis) test technology to test and verify the shifting performance of a domestic automobile gearbox, establishes the subjective and objective evaluation criteria for the shifting performance of automobile gearbox, provides a reliable theoretical basis for product optimization design and shifting performance evaluation, and formulates shifting control pertinently. Strategies and optimization measures to ensure that the power, ride, and transmission of the whole vehicle system meet the technical requirements and can shift quickly and smoothly. Not only does this allow to reduce the driver’s fatigue strength, but also increases the comfort of the whole shifting process, so as to provide direction to improve the quality of the vehicle’s shifting performance and effectively reduce the impact on the driver’s health.

KEYWORDS
automotive transmission, data information analysis, GSA, optimization control, shifting performance test

1 INTRODUCTION

In the traditional passenger vehicle market where the proportion of automatic transmission application is increasing gradually, manual transmission still has a broad market space in the 21st century and beyond because of its stability, reliability, simple structure, and high cost performance.

The poor performance of manual transmission in automobile would reduce the driver’s driving pleasure and make the driver feel tired. Especially in urban conditions, the driver is very sensitive to the comfort of gear selection performance because of the uninterrupted shifting action, which directly affects the driver’s evaluation of a certain type of vehicle.¹⁻³ It can be said that as a user’s perceptible item, the shifting performance of transmission is directly related to the degree of user complaints. Therefore, in order to meet the needs of consumers, automobile manufacturers need to improve
the shifting quality and driving comfort as much as possible through continuous design optimization in the process of transmission development and matching.4

As early as 1989, Volkswagen Corporation, GM Company, and Steyr Company began to study the comprehensive test-bed of transmission system which can simulate the driving conditions of automobiles. Through gear shifting performance test, the driving maneuverability of the vehicle can be assessed and evaluated, so as to provide a scientific theoretical basis for product design and optimization, shorten the development cycle, reduce the cost of research and development, and improve the quality of automobiles.5

In the early stage, the shifting performance test of automobile transmission was divided into road test and bench test.6 Because road test is greatly influenced by natural factors, the test cycle is long and the cost is high, so it is an inevitable trend to develop transmission shifting performance test bench. With the rapid development and wide application of virtual instrument sensors and other technologies, bench test of gearshift performance of automotive transmission with high accuracy and integration characteristics has gradually become the main test means.7,8 Among them, the comprehensive test-bed developed by Volkswagen in 1991 can carry out the life test of transmission, clutch, transmission shaft, and rear axle at the same time.9 However, the price of transmission shifting performance test-bed developed abroad is generally expensive, which makes many enterprises hesitate. A lot of research on shifting performance bench tests of transmission has been done in China, which are widely used in the field of development and application of manual transmission.10,11 It involves the construction of the hardware platform of the test bench and the software development of the measurement and control system. The test data mainly include the gear selection and shifting force (travel). The relationship curve between the gear shifting force and the displacement can be obtained through offline analysis to evaluate the shift quality. However, the design of the shifting test bench adopts artificial control mode, lacking detailed synchronizer model, and vehicle system environment in simulation, which is not only inefficient, but also low cost-effective. In addition, different personal control habits and subjective feelings affect the objectivity of data and are not conducive to evaluating the gear shifting performance of shift lever.

For this reason, this paper would combine the advanced transmission shifting test theory and method of at home and abroad, introduce gear shift analysis (GSA) test system on the basis of existing vehicle transmission shifting performance bench test. It would further explore the evaluation method and improvement measures of dynamic shifting performance of manual transmission, and debug the most appropriate operational performance by reflecting the data on the test software (as shown in Figure 1). In addition, we apply it to a domestic manual transmission passenger vehicle for objective test of shifting performance, combining with the subjective test evaluation experience of previous projects, to establish a relatively perfect objective test evaluation indicator. The subjective and objective evaluation process of shifting performance can help designers evaluate the shifting performance of manual transmission systematically and comprehensively at all stages of development. Explaining subjective phenomena by objective testing can more intuitively observe the data reflection of shifting performance under various working conditions, adjust the most comfortable shifting performance parameters, and then systematically improve the product shifting performance and improve vehicle driving comfort.

With an increasing number and diversification of powertrain setups, the evaluation of drivability is a major challenge in the vehicle development process.12,13 Since the comprehensive tests with prototype vehicles are complex, time-consuming and expensive, using GSA test technology for drivability evaluations of automobile transmission is a promising alternative. As a powerful cutting-edge tool for evaluating drivability in a fast and cost-effective way, it could enable concept evaluations in early development stages, offer a high degree of reproducibility and controllability regarding the test conditions, and provide guidance for transferring results to real world conditions. In this paper, the effect of objective test evaluation indicator in the context of drivability is analyzed with GSA test technology. The aim is to provide strong support for systematic improvement of automobile transmission shifting performance, facilitate to guide the formulation of relevant improvement measures, help to save a lot of time and resources, and reduce the number of optimization and tests in the later stage, and then reaches the purpose of decreasing cost and shorting development cycles.

FIGURE 1 Shifting test system of the whole vehicle
The presented work helps to enhance existing research, and its related methods and conclusions would help to further improve the design matching relationship of automobile transmission, and provide reference for the later development of high-end new products of enterprises.

2 | VEHICLE SHIFTING SYSTEM TESTING

At present, there are two main ways to test and evaluate the performance of automobile variable speed control system: subjective test evaluation and objective test evaluation. The objective test evaluation is divided into static test evaluation and dynamic test evaluation.¹⁴

2.1 | Subjective test evaluation

In the past, the shifting performance evaluation of the vehicle with manual transmission mostly adopts subjective evaluation. In the static and running state of vehicles, the experienced drivers subjectively test and score the performance of gear selection, and take the subjective comprehensive score of each performance as the evaluation indicator. This would not avoid the randomness and limitations of the evaluation. The evaluation results are related to the driving habits and preferences of the evaluators, which cannot objectively reflect the problems existing in the shifting process of vehicles, so it is difficult to help the designers to find the optimal design solutions.¹⁵

2.2 | Static test evaluation

When the vehicle is stationary and the engine is shut down, the gear selection and shifting force and travel at the ball head of the control handle are taken as the evaluation indicators. At present, static test evaluation is widely used in domestic automotive transmission manufacturers, and it is also the preferred way to test and evaluate the performance of gear selection and shifting.¹⁶,¹⁷

Because the transmission gear is in a static state during the measurement, it has no effect on the selection and shifting of gears, while the customers are in the vehicle operation and the transmission working state to select and shifting gears. Therefore, the static test and evaluation cannot reflect the performance of the vehicle in the running state, which is contrary to the use of customers, and there are irreparable loopholes.

2.3 | Dynamic test evaluation

Based on the current static evaluation and subjective evaluation, the dynamic evaluation from GSA test technology in this paper is introduced through the real-time measurement of the force, travel, acceleration, and other important parameters of the shift lever knob, and then we systematically evaluate the performance of the gear shift processes from the aspects of the selection and shifting force, gear clarity, free play, dynamic impact, and so on. Among them, GSA high quality force knob sensor is used to acquire high accuracy force values in shift, select, and vertical direction, and GSA travel measurement unit is used to acquire shift and select travel of the shift knob. In addition, we also use a high quality measurement device made in Germany by IMC, the software for acquisition of the signals from the sensors, and the online displays for sensor verification and gear shift counting, as shown in Figure 2.

Usually, the corresponding measurement procedures include installing GSA hardware acquisition equipment in the test prototype, recording test data by data acquisition instrument, transforming the collected analogy signals into directly readable information by means of acquisition software, and finally analyzing and evaluating the shifting characteristics by GSA analysis tool. The main test links include:

1. **Gear Clarity.** In general, the users of manual vehicles are more sensitive to the gear clarity, because the poor gear clarity would cause gear shifting stuck or even disordered. The main evaluation method of the gear clarity is the definition of H pattern. H pattern is the gear arrangement in the automobile transmission. Its shape is like the letter H, so it is called H pattern. Generally, H pattern test is an important index for evaluating the gear clarity, which is obtained by measuring the shift trajectory at the shift lever.¹⁸
2. **Selection and Shifting Force.** The function module is used to test the gear selection and shifting force and travel range. Gear shifting force refers to the resistance that the control lever knob needs to overcome when engaging a certain gear position. Gear selection force refers to the resistance that the control lever knob overcomes when selecting the left or right gear position. A good gear selection curve must start with a rapid increase in gear selection force and then remains constant until the gear limit.

3. **Free Play.** The size of free play directly affects the accuracy of gear selection. It reflects the free shaking amount of each gear position, which can be said to be the concentrated reflection of the clearance between the external and internal gearshift system. If the free play is too large, it would have a greater impact on the accuracy of gear shifting, which would lead to difficulty in finding gear, however, too small would cause the shifting operation to be stiff, inflexible, or even out of gear, making the driver feel uncomfortable.

4. **Dynamic Shifting Impact.** The function module is used to test whether the synchronous impulse is too large, the synchronous time is too long, and the synchronous capacity is too low. If the synchronous operation cannot be completed in time, the driver may feel difficult to shift. 19

5. **Synchronous Capacity.** In order to shift into a certain gear, the minimum friction torque which the synchronizer must provide to complete the synchronization process within the specified time is called the synchronous capacity required in the shifting process. 20

### 3 | SHIFTING PERFORMANCE OPTIMIZATION ANALYSIS

In theory, this part of the research would be carried out by using the knowledge of relevant disciplines. First, this paper analyzes and explains the basic structure and working principle of automobile transmission shift system, and constructs the evaluation theoretical system and overall research framework of GSA shift test. Second, with the help of GSA test technology and bench test, the shift performance evaluation analysis model of the whole vehicle is constructed in accordance with the actual working conditions. Third, according to the performance attributes of each gear and its influencing factors, the shift control strategy based on the transmission shift quality is formulated, so as to seek the optimal matching design between the shift control system and the shift mechanism parameters. And finally we would establish the optimization method of vehicle shift control system that conforms to the customer’s subjective experience.

According to the engineering practice in the development process of the passenger vehicle, the shifting performance indicator of the manual transmission is sorted out and discussed. The preliminary evaluation and optimization analysis of the shifting design are carried out. The key points of the possible problems in the research object are found through GSA test, and then the corresponding solutions are formulated. In this paper, the contrast test of the vehicle shifting performance before and after the improvement would be carried on under the actual working conditions. The key hardware of the shifting mechanism after structural optimization is debugged on the test prototype, and then GSA retest is carried out to check whether the gear clarity has been improved significantly, whether the free play meets the requirements, whether the synchronous capacity is increased significantly, and whether the synchronous impulse of dynamic shifting is reduced, and so on. Through the test results to verify the rationality and effectiveness of the solution measures formulated by this project, and then form a shifting optimization test analysis path based on GSA test technology.
4 | SHIFTING PERFORMANCE TESTING ANALYSIS

GIF Gesellschaft für Industrieforschung is an automotive company based out of Germany, covering the vehicle transmissions and the design, testing, and development of powertrain system. GSA system, which was developed by GIF, has proven in many years of testing to be a valuable tool, mainly by complex transmission and gear development projects. GSA system is not only applied for objectively assessing the change of gears in a vehicle, but also permits measuring and analyzing the influencing factors of gear shifting quality. Therefore, during the new development and integration of transmissions, transmission component testing, and quality assurance, GSA system is indispensable as the right tool.

Based on GSA shifting performance test evaluation system, this project completes the control strategy research of improving the shifting quality of automobile transmission. The technical route to be adopted is shown in Figure 2. The development process of transmission shifting performance is mainly divided into scheme design stage, performance prediction stage, platform construction stage, performance optimization stage, and popularization application stage, as shown in Figure 3. First, the research idea is clear, the research scheme is determined, and the theoretical research framework of shifting test and evaluation is constructed. Second, relevant materials are collected, the performance parameters of transmission and shifting control mechanism are summarized, and the shifting performance of the whole system is predicted. Third, the shifting control performance bench test and GSA test system are built to carry out the subjective and objective test and research of shifting performance, and the real-time acquisition of shifting performance is carried out. The performance indicators in the process are analyzed and evaluated to provide data support for improving the shifting performance of the system. Then the optimization improvement measures are specified and the shifting performance is re-evaluated to obtain the best matching relationship of the shifting performance and verify the effectiveness of the control strategy research scheme. Finally, the shifting optimization test and analysis path based on GSA test technology is formed.

GSA test analysis means that the whole test system includes hardware acquisition equipment and software processing analysis tools. Through real-time measurement and analysis of the force, travel, acceleration, and other important parameters of the shifting lever knob, the performance of the whole vehicle is systematically evaluated from the aspects of the shifting and selection force (travel), system stiffness, free play, and dynamic impact.

4.1 | Gear shifting force

The gear shifting force is composed of the in-gear force and the off-gear force. The in-gear force refers to the maximum resistance encountered by the shift lever knob in the process of entering the vehicle’ gear position, while the off-gear force refers to the maximum resistance encountered by the shift lever knob in the process of getting out of the vehicle’ gear position. Usually, there is a correlation between the shifting performance and the driving experience of the whole vehicle. The gear shifting performance could be evaluated from the following aspects: the characteristics of the gear shifting force, the inhalation sensation, and the sense of leaning against the wall when hanging in place. Among them, the so-called

![Figure 3](image-url)
Inhalation sensation is that we hope that the shift lever knob could overcome a reverse force during shifting operation, and then automatically enter or exit the gear position, so as to reach the ideal free position. The phenomenon that this reverse force appears in the shifting process is called the inhalation sensation. Good inhalation sensation can make the shifting operation smooth without blocking feeling, and improve the feeling and fun of the driving operation.

The Detent module of GSA is used to test the gear shifting performance. The actual shifting performance curve is shown in Figures 4, 5, and 6. The final test data are shown in Table 1. From the table, the results of the most important aspects and the leanings are described and explained as follows:

1. The shifting in-gear/off-gear force of each gear is suitable. Especially for N-4-N situation, the shift positioning block rolls on the upper surface of the shift fork, which bevel angle is relatively large, resulting in a relatively small gear shifting force.
2. The shifting travels of each gear are comparable.

**FIGURE 4** 1/2 Gear characteristic curve

**FIGURE 5** 3/4 Gear characteristic curve

**FIGURE 6** 5/R gear characteristic curve
TABLE 1 The shifting performance test data of three gears

| Transmission assembly model | Item                  | Test gear N-1-N | N-2-N | N-3-N | N-4-N | N-5-N | N-R-N |
|-----------------------------|-----------------------|-----------------|-------|-------|-------|-------|-------|
|                             | Maximum in-gear force-N | 27              | 23    | 24    | 15    | 26    | 24    |
|                             | Maximum off-gear force-N | 24              | 28    | 22    | 17    | 19    | 20    |
|                             | Shifting travels-mm    | 68              | 69    | 70    | 69    | 69    | 71    |
|                             | Inhalation sensation   | Not obvious     | Not obvious | Not obvious | Not obvious | Not obvious | Not obvious |
|                             | Sense of leaning against the wall | Obvious | Obvious | Obvious | Obvious | Obvious | Obvious |

3. The consistency of the characteristic curve of each gear is good. It shows that the whole shift process should be relatively smooth, without obvious fluctuations and sudden peak.

4. Inhalation sensation of each gear was not obvious. This may cause the unsmooth shift operation, as well as sense of blockage, affecting the feeling of driving operation.

4.2 Gear selecting force

To a large extent, the driver’s operating feeling and the vehicle’s dynamic shifting performance are related to the vehicle’s gear selecting characteristics. Ideally, the gear selecting force gradually increases from the gear free position, tends to be constant or slightly decreases after reaching the peak value. Then, in the process of returning to the gear free position from the gear end position, the selecting force, also known as the return force, should be above 0 N to ensure that the gear lever knob can return automatically.

In generally, the slope of the selecting force curve should not be too small or too large. At the same time, it shall be smooth without fluctuation, and have good overall consistency as much as possible. If the slope of the gear selecting force curve is too small, the free play of the gear selection would be too large, and if the slope is too large, the gear selecting force would be too large, which would affect the operation.

The actual selection performance curve is shown in Figure 7. The final test data are shown in Table 3. From Table 2, it can be concluded that:

1. The selecting force of each gear is suitable, the selection process is smooth and there is no inflexible phenomenon.
2. The selecting force curve could be well developed horizontally, and the consistency of gear selecting curve is good, and the sense of leaning against the wall is obvious.
3. The selecting travel of each gear is inconsistent, and their values are still a little different.
### TABLE 2 The selecting performance comparison data of three gears

| Transmission assembly model | Item                        | Test gear |
|-----------------------------|-----------------------------|-----------|
|                             | N-1/2                       | N-5/R     |
| Maximum selecting force-N   | 34                          | 30        |
| Maximum restoring force-N   | 7                           | 7         |
| Selecting travels-mm        | 47                          | 55        |

#### 4.3 Free play and H pattern

Due to the errors in manufacture and assembly, the free play is inevitable in the whole shifting system of automobile transmission. The appropriate free play can ensure the accuracy of the gear shifting and good driving feeling. Therefore, how to control the free play of the shifting system so that the shifting lever knob could move within a reasonable range has become an important concern in the design of the shifting system.

H pattern could clearly show the boundary of each gear, and could see the free position of the shifting ball head in each gear and the actual shifting track. In an ideal state, the free position of the shifting ball head should coincide with the actual shifting track. A good H pattern evaluation standard is that there is no or little overlap between H pattern boundaries of each gear, and it would be considered that the vehicle’s clarity of gear position is better.

Therefore, it is easy to see the rationality of each position by combining the free play and H pattern together. The actual diagram of H pattern and free play is shown in Figure 8. The final test data are shown in Table 3. From the table, it can be concluded that:

1. There is about 15% overlap in adjacent gear areas, which arrangement is relatively neat and does not cover the free play, so it can be said to have better vehicle’s clarity of gear position.
2. The free play of each gear has a similar area and is relatively small, which could ensure the accuracy of the shift and meet the accuracy control requirements of the shift lever knob.

**FIGURE 8** The actual diagram of H pattern and free play

| H-pattern and free play diagram under 10 N force (mm) |
|------------------------------------------------------|
| Transmission assembly model | Test gear | N  | 1  | 2  | 3  | 4  | 5  | R  |
|                            |           | 28 × 20 | 28 × 40 | 25 × 30 | 30 × 40 | 27 × 27 | 28 × 30 | 20 × 20 |

**TABLE 3** H pattern and free play diagram under 10 N force
4.4 | Cross shifting

In the process of shifting, the power interruption time is an important indicator of the shifting performance, which requires the shifting system to achieve the shifting between gears in the shortest time. For the adjacent gears of the cross arrangement, it is necessary to realize the cross shifting in the design of internal shifting system. Therefore, by designing a certain angle in the shifting fork head, it can play a guiding role in cross shifting and achieve good cross shifting performance.

The performance of cross shifting, as an indicator of measuring the shifting system, depends on the internal structure design of the operating system and the quality of the parts. The actual diagram of the cross shifting is shown in Figures 9 and 10. From the diagram, it can be concluded that:

1. There is obvious abnormal shifting force in the shifting process from 3 to 2 gear, which indicates that there is the clamping stagnation in the shifting process.
2. There is obvious abnormal shifting force in the shifting process from 4 to 5 gear, which indicates that there is the clamping stagnation in the shifting process.

The so-called clamping stagnation here refers to the unsmooth and inflexible phenomenon existing in the shifting process, that is, the shifting force increases in a certain period of time, while the shift handball does not move. This feeling is equivalent to pushing the rigid body by hand, resulting in extremely uncomfortable shifting operation, which will easily cause complaints from the drivers.

**Figure 9** The actual diagram of cross shifting (2-3-2)

**Figure 10** The actual diagram of cross shifting (4-5-4)
4.5  |  Shifting and selecting rigidity

The stiffness characteristic of the automobile shifting system is a comprehensive representation of the deformation ability of the whole shifting system at the shift lever knob. The stiffness of the shifting system is composed of the shifting stiffness and the selecting stiffness, which is another indicator for evaluating the shifting system. Appropriate level of the shifting and selecting rigidity can reduce the clamping stagnation of gear shifting and secondary impact. However, with the increase of the shifting and selecting rigidity, the subjective feeling of the shifting operation would be reduced. Therefore, it is very important to design the appropriate shifting and selecting rigidity. In general, considering the clearance of the shift system, the stiffness of the shift system is calculated from the moment when the force applied to the shift lever knob is about 30 N, so as to obtain relatively stable system stiffness.

The actual shifting rigidity and selecting rigidity are shown in Figures 11 and 12. From the graph, it can be concluded that:

1. The shifting rigidity recommended by GIF is 5 N/mm-8 N/mm, and the actual measured values are 3.5 N/mm and 5.07 N/mm. The forward shifting rigidity of the system is small.
2. The selection rigidity recommended by GIF is 4 N/mm-6 N/mm, and the actual measured values are 4.62 N/mm and 5.63 N/mm. The selection rigidity of the system is suitable.

5  |  RESULTS ANALYSIS

This paper uses GSA testing system to test the shifting performance of the manual transmission and analyses the test data through the fitting process to form a series of parametric change curves, which transforms the subjective evaluation into objectively quantitative analysis for the shifting performance test and directly finds out the performance improvement items. From the results of calculation and the evaluation of the real vehicle, the following problems exist in the shifting performance of the vehicle:

![Figure 11](image1)  |  The rigidity of shifting direction

![Figure 12](image2)  |  The rigidity of selecting direction
1. No inhalation during shifting.
2. There is a high probability of the shift clamping stagnation during cross shifting operation.
3. When 1/3/5 gear is mounted, the deformation of the gear shifting system is relatively large.

Aiming at the above problems, it is feasible to improve the shifting operation performance of automobile transmission by adjusting the transmission structure and related design parameters, which mainly involves the following aspects:

1. The shifting inhalation sensation can reduce the distance of the drivers’ moving the transmission rod, reduce the shifting force relatively and increase the shifting feel, at the same time, it can attenuate the vibration from the gear shaft and improve the driving comfort. In this case, it is suggested to consider adding the shifting position blocks and linear bearings to improve the shifting inhalation sensation.
2. The function of interlocking plate is to avoid shifting two gears at the same time. When the size of interlocking plate is abnormal, a slight deviation in the selection position would cause the dialing blocks of each gear to be stuck by interlocking plate, resulting in the failure of the shifting head to move the dialing blocks and the occurrence of the shift clamping stagnation phenomenon. In this case, it is suggested to consider improving the structure of interlocking block and shifting head to eliminate the shift clamping stagnation.
3. It is suggested to consider adding the rigid shifting arm with inertia block to improve the larger deformation of the gear shifting system.

Generally speaking, this paper describes the working principle of GSA test system in detail, and combines with the actual case of the cooperation units, makes a systematic analysis of the faults in the shifting process of a certain automobile transmission, thus finds out the elements of design improvement, points out the key points of each element that should be paid attention to, and puts forward effective methods to improve the shifting performance and reduce the shifting force.

6 CONCLUSIONS

As an important part of the vehicle, the quality and matching application of the manual transmission directly affect the driving and comfort of the vehicle. With the growing maturity and high-end of the domestic manual transmission passenger vehicle market, the requirements of variable speed control comfort also increase. In order to continuously improve the comfort of variable speed control, the first step is to adopt a reasonable performance test method. Only by adopting more objective test evaluation methods, which is closer to customers’ usage habits, can the researchers accurately find out the shortcomings of the system and then take the targeted optimization measures. Therefore, how to test and evaluate the performance of variable speed control system comprehensively and accurately is the first problem to improve the comfort of variable speed control. This paper would combine the engineering practice demand of a domestic passenger vehicle research and development, explain subjective evaluation phenomena with objective data by GSA test technology, quantify the driver’s subjective feelings into objective data, that is to say, the objective indicators regarding the driving comfort are considered in order to evaluate the possible drivability improvements related to the sensitivity of shifting dynamics parameters. This would provide strong support for systematically improving the product shifting performance and facilitate the formulation of relevant improvement measures. For cooperative units, this project would play an active role in improving the selection and shifting performance of passenger vehicles with manual transmission. The relevant methods and conclusions would help to further improve the design matching relationship of automobile transmission, and provide reference for the later development of high-end new products of enterprises. The research results of this project would also radiate to the entire automotive industry, providing theoretical guidance and methodological reference for promoting the improvement of gear shifting performance in China’s automotive industry.

ACKNOWLEDGEMENTS

This work was supported by National students’ platform for innovation and entrepreneurship training program under Grant ZC306919012, Scientific and technological innovation plan for college students of Zhejiang province under Grant 2020R404057, Zhejiang Province Soft Science Research Project under Grant 2020C25G2030615.

PEER REVIEW INFORMATION

Engineering Reports thanks the anonymous reviewers for their contribution to the peer review of this work.
CONFLICT OF INTEREST
The author declares no potential conflict of interest.

AUTHOR CONTRIBUTIONS
Wenquan Shen: Conceptualization; methodology. Qiugui Zhang: Resources; supervision. Zhenwen Chen: Data curation; formal analysis. Wei Mao: Funding acquisition. Yongxiang Li: Conceptualization; formal analysis; methodology; validation; writing-original draft; writing-review and editing.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID
Yongxiang Li https://orcid.org/0000-0002-3888-9170

REFERENCES
1. Huang W, Liu HJ, Li M, et al. A research on evaluation method for vehicle drivability quality in start condition. Automob Eng. 2018;40:1324-1329.
2. Castellazzi L, Tonoli A, Amati N, et al. A study on the role of powertrain system dynamics on vehicle drivability. Veh Syst Dynam. 2017;55:1012-1028.
3. Huang W, Liu HJ. Application of fuzzy dynamic weights drivability evaluation model in tip-in condition. J Vib Control. 2019;25:739-747.
4. Chen SY, Hung YH, Wu CH. An integrated optimal energy management/gear-shifting strategy for an electric continuously variable transmission hybrid powertrain using bacterial foraging algorithm. Math Probl Eng. 2016;2016:1495732. https://doi.org/10.1155/2016/1495732.
5. Mi L, Wang HZ, Tan W. Design of testing and controlling system for shifting performance of commercial vehicle transmission. J Chongqing Univ Technol. 2018;32:21-27.
6. Ma LY. Bench test development of vehicle ride comfort based on road simulation. Lab Res Explor. 2017;36:80-83.
7. Duque EL, Aquino PT. Human factors analysis of manual gear shifting performance in passenger vehicles. Procedia Manuf. 2015;3:4350-4357.
8. Huang H, Gühmann C. Model-based gear-shift optimization for an automated manual transmission. Proc Inst Mech Eng D J Automob Eng. 2018;233:1-10.
9. Li H. Research on Testing Bench for Automotive Transmission Assembly. Tianjin, China: Tianjin University; 2004.
10. Zhong ZM, Kong GL, Yu ZP. Construction and test analysis of static shift load test platform for transmission. Automob Eng. 2011;33:787-791.
11. Zhong ZF, Lu J. Shifting performance analysis of gearbox synchronizer based on bench test. J Mech Transm. 2017;41:138-143.
12. Chipka JB, Campbell M. Estimation and navigation methods with limited information for autonomous urban driving. Eng Rep. 2019;1:e12054. https://doi.org/10.1002/eng2.12054.
13. Kramarz KD, Przybylska E. Scenarios for the development of multimodal transport in the TRITIA cross-border area. Sustainability. 2020;12:7021.
14. Ouyang T, Li SY, Huang GC. Controller design for uncertain dynamics of smooth shift of heavy-duty automatic transmission. Appl Math Model. 2020;85:157-173.
15. Liu XJ, Sun DY. An improved design of power-cycling hydrodynamic mechanical transmission. J Mech Sci Technol. 2020;34:3165-3179.
16. Huang W, Liu HJ, YF M. Drivability evaluation model using principal component analysis and optimized extreme learning machine. J Vib Control. 2019;25:2274-2281.
17. Baumgartner E, Ronellenfisch A, Reuss HC, Schramm D. A perceptual approach for evaluating vehicle drivability in a dynamic driving simulator. Transport Res F Traffic Psychol Behav. 2019;63:83-92.
18. Ebenhoch M, Krieg WE, Kubalczyn R, et al. Modular transmission system for a MT, AMT and DCT based on a common wheelset. VDI Berichte. 2004;1827:51-64.
19. Yang SQ, Wang Y, Evaluation LJW. Improvement strategy of dynamic gear shift performance of passenger car with manual transmission. Chin J Automotive Eng. 2012;2:348-353.
20. Haggestrom D, Selligren U, Bjorklund S. Evaluation of synchronizer loading parameters and their ability to predict failure. Proc Inst Mech Eng J J Eng Tribol. 2018;232(9):1093-1104.
21. GSA gear shift analysis, ATESTEO GmbH & Co. KG. [Online]. https://www.atesteo.cn.com/ceshishebei/gsahuandangfenxi/.

How to cite this article: Shen W, Zhang Q, Chen Z, Mao W, Li Y. Testing and analysis of automotive gearshift performance based on gear shift analysis. Engineering Reports. 2021;3:e12324. https://doi.org/10.1002/eng2.12324