Journal of Engineering Mechanics and Machinery (2022)
Clausius Scientific Press, Canada
DOI: 10.23977/jemm.2022.070303
ISSN 2371-9133 Vol. 7 Num. 3

# *Overview of Spindle-Coupled Road Simulation Test Method for Vehicle Structure Durability*

**Guang Yang[a,*], Zhiqiang Zhao[b], Zhihui Niu[c], Yongzhe Wang[d]**

*CATARC Automotive Test Center (Tianjin) Co., Ltd., Tianjin, China*
*[a]yangguang2015@catarc.ac.cn, [b]zhaozhiqiang@catarc.ac.cn, [c]niuzhihui@catarc.ac.cn, [d]wangyongzhe@catarc.ac.cn*
**Corresponding author*

***Keywords:*** Vehicle, Structure durability, Spindle-coupled, Road simulation test

***Abstract:*** The durability of vehicle structure is one of the important performances to evaluate the quality of automobiles, and it has been paid more and more attention by automobile manufacturers and consumers. In the whole vehicle development process, automotive structural durability testing is essential. With the advantages of high test accuracy and short test cycle, road simulation test has become an effective test method in the vehicle development stage. Among them, the spindle-coupled road simulation test can most comprehensively reproduce the excitation of the road to the vehicle. The relevant test technology is synchronized with the rapid development of automotive products and keeps pace with the times, becoming one of the most deeply cultivated test technologies in the industry.

## 1. Introduction

The structural durability of automobiles is an important criterion for evaluating the excellent quality of automobiles. Its meaning refers to the ability of automobiles to perform specific functions when they reach the limit of a certain technical or economic index under specified conditions of use and maintenance. The automobile industry is experiencing rapid development. How to quickly and accurately verify the structural durability of new models is an urgent problem for companies. In the development process of automobile structural durability, three technical verification methods are usually adopted: real vehicle road test, laboratory bench durability test and CAE analysis. Among them, the real vehicle road test is the closest to the real fatigue results, but the cycle is long and the cost is high; CAE analysis technology has limited prediction accuracy due to the constraints of theory and the error of input conditions. With the road simulation technology, the laboratory bench durability test can accurately "move" the proving ground into the laboratory, which can avoid the influence of the external environment, and greatly shorten the whole vehicle development cycle while obtaining accurate results [1]. At present, the road simulation test of automobile structure durability in the industry is roughly divided into two categories: spindle-coupled road simulation test and wheel-coupled road simulation test. The former is based on the spindle-coupled road simulation bench (24 channels), which reproduces the six degrees of freedom of each wheel, and varify the durability of automobile chassis and body-in-white; The latter is based on the wheel-coupled road simulation test bench(four-poster), which reproduces the vertical degree of freedom of the wheels and quickly completes the assessment of the automobile body-in-white and related accessories. This paper focuses on the introduction of the spindle-coupled road simulation test method.

## 2. Conventional spindle-coupled road simulation test methods

At present, the RPC (Remote Parameter Control) technology and equipment introduced by the American MTS company are widely used internationally when the spindle-coupled road simulation test is carried out in the laboratory. The system mainly includes computer, control system, sensors and actuators. Using RPC technology, after several iterations, the excitation signals of different road surface characteristics are reproduced on the six-degree-of-freedom(6-DOF) spindle-coupled road simulation test bench.

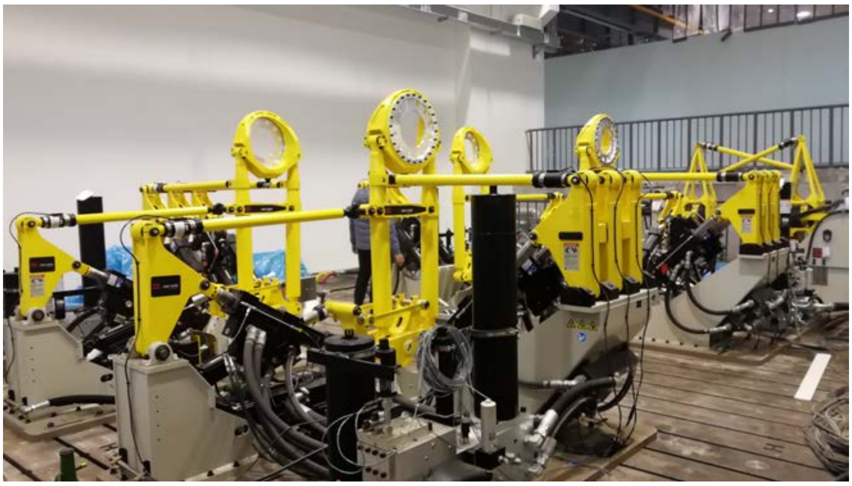

Figure 1: Spindle-coupled road simulation test bench

Table 1: System performance of MTS329PC

| | Vertical input | Longitudinal input | Lateral input | Steer input | Brake input | Camber input |
|---|---|---|---|---|---|---|
| Max.Operating Frequency | 50Hz | 50Hz | 50Hz | 50Hz | 50Hz | 50Hz |
| Spindle Force | 63 kN | 22 kN | 20 kN | 4 kN.m | 4 kN.m | 4 kN.m |
| Spindle Displacement | 380 mm | 392 mm | 258 mm | 16° | 32° | 16° |
| Spindle Velocity | 7 m/s | 2.2 m/s | 2.4 m/s | 700°/s | 700°/s | 400°/s |

The 6-DOF spindle-coupled road simulation test bench is a complex series-parallel hybrid mechanism, as shown in Figure 1. Through the 6-DOF spindle-coupled vehicle road model test bench, multi-axial forces and displacements are applied to the passenger car, light truck or vehicle suspension system. Thereby, the fatigue characteristics of the test vehicle or component are obtained. The road simulation test machine of the passenger car version (MTS329PC) is aimed at vehicles with a maximum total mass of less than 3000kg, and its performance indicators are shown in Table 1. In recent years, the structural durability verification of commercial vehicles has also been carried out in the laboratory. Therefore, MTS has launched a road simulation test machine of the light truck version (MTS329LT). The maximum mass of the vehicle is about 6000Kg, which greatly broadens the scope of the test vehicle.

The spindle-coupled road simulation test is roughly divided into four stages: road load data acquisition, system model identification, drive file development and test execution.

### 2.1. Road load data acquisition

Real vehicle road load data acquisitionn means that the test vehicle is installed with wheel force sensor, spindle and body acceleration sensor, displacement sensor, strain gauge, etc. Time-domain signals such as force, deformation, relative displacement and impact acceleration of vehicle components under road conditions in the proving ground is obtained. In the process of reliable and durability development of modern automobiles, road load data acquisition of real vehicles is widely used. Whether it is the fatigue CAE analysis and checking of components in the early stage of development, or the verification of vehicle durability performance in the product verification stage, road load data acquisition needs to be applied.

### 2.2. System model identification

By setting frequency information and amplitude information, a white noise signal is generated and the system is excited. Calculate the frequency response function matrix *H(f)* of the system according to the excitation signal and the measured response signal. The road simulation bench and test vehicle can be regarded as a linear system with multiple inputs and multiple outputs, and the expression of the frequency response function matrix *H(f)* is:

Frequency response function matrix *H*(*f*) is:

$$Y(f)= H(f)\, X(f) \tag{1}$$

Where: *X*(*f*) is the drive signal spectrum, *Y*(*f*) is the response signal spectrum.

The linear relationship of the power spectral density matrix of the multi-input multi-output linear system is:

$$G_{xy}(f) = H(f)\, G_{xx}(f) \tag{2}$$

In the formula: $G_{xx}(f)$ is the auto-power spectrum of the driving signal, and $G_{xy}(f)$ is the cross-power spectrum of the driving signal and the response signal.

*H*(*f*) is calculated according to the white noise driving signal and the corresponding response signal. The quality of the frequency response function affects the accuracy of subsequent iterations. Its inverse and the target signal operation can obtain the drive signal of the bench:

$$Xn(f)= H^{-1}(f)\, Y_D(f) \tag{3}$$

In the formula: $H^{-1}$ is the inverse of the frequency response function *H(f)*, $Y_D(f)$ is the target signal spectrum, and $X_n(f)$ is the driving signal spectrum.

### 2.3. Drive file development

Since the whole test system inevitably contains nonlinearity in the test vehicle, control system and other links, and the iterative response is calculated according to the linear system, there must be errors between the iterative response and the target response. Generally, through several iterations, the driving signal is continuously corrected, so that the response signal of the system is infinitely close to the target signal. The indicators to measure the success of the iteration include the time domain comparison, the frequency domain comparison and the damage comparison between the target signal and the iterative response signal. The higher the iteration accuracy, the closer the bench excitation effect is to the actual road excitation effect, and the higher the test accuracy obtained.

## 2.4. Test execution

Based on the durability specification, compile the drive sequence and times of all drive signals, and consider the cooling of damper and bushings, and it is possible to appropriately add the cooling time during severe road conditions. In order to ensure that the force status of the car can be monitored in real time, all the sensors during the iteration, including the wheel force sensor, the internal force strain gauge of the rod and the suspension displacement sensor, are retained during the bench durability process, and set the protection limit according to the monitoring signal type. In general, the allowable change for force signal is 1 kN, that in torque signal test operation is 0.3 kN.m, and that in displacement signal test operation is 2 mm. As the endurance test progresses, the magnitude of the allowable change is updated in real-time based on the actual analysis.

## 3. Road simulation test technology of suspension based on virtual load

During the whole vehicle development process, the suspension system is developed earlier, so the structural durability verification is carried out at the suspension level earlier. At present, the spindle-coupled road simulator is widely used in the industry to carry out indoor tests, which can not only greatly shorten the development cycle, but also accurately identify potential problems. There are generally three sources of input data for the suspension bench durability test: standard sine spectrum, real vehicle load, and virtual load. The standard sine spectrum can be applied to different types of suspension systems by changing the amplitude, frequency and number of cycles, which is easier to reproduce, but less targeted. The load spectrum of the real vehicle truly reflects the force and motion status of the vehicle, and is the best input for the bench test. The virtual load is that the "assembled" virtual model of the vehicle model, driver model, tire model, etc. "drives" on the road surface model, so as to obtain various loads of the parts. When such models reach a certain accuracy, the virtual load can be directly applied to the bench test [1-5]. In addition, for changes in the characteristics of components in the design process, the virtual load can also be corrected in the shortest time and at the lowest cost. The virtual load is more and more widely used in the bench durability test.

## 4. Hybrid road simulation test method

In recent years, OEMs institutions have tried to use computer virtual simulation technology to deal with engineering problems, but it is difficult to accurately create mathematical models for most nonlinear elastic components. Hybrid System Response Convergence (HSRC, HSRC for short) iterative technology is a hybrid simulation iterative technology that skips the complex mathematical modeling process and uses the real physical model of the real vehicle. Road Test Simulation (RTS) real vehicle model, FTire tire model and virtual road surface are combined to build a real-virtual hybrid model, using physical quantities such as force and displacement as the signal communication interface, the test prototype can be reproduced step by step iteratively testing the motion attitude and load on the road surface in the proving ground provides an effective technical means for the rapid development of the driving signal of the bench durability test.

At present, HSRC technology is mainly used by developed countries such as the United States and the United Kingdom. There is no much domestic case of introducing this technology. HSRC technology was first proposed by MTS Company at Vehicle Dynamic Expo in 2010. The hybrid simulation technology means HSRC improved by Fricke team can abandon the high hardware requirements of traditional hybrid simulation technology relying on real-time simulation, so as to perform durability tests more effectively and faster, the simulation accuracy results are greatly improved compared with the fully virtual computer simulation.

At present, the domestic spindle-coupled vehicle road simulation test is still in the emerging period in the field of structural durability testing. Many OEMs have built their own spindle-coupled vehicle road simulation test machines. The trust and benefit of the vehicle road simulation technology will gradually increase, which will inevitably increase the investment in this field by the R&D funds of the OEMs. But on the other hand, with the growing demand for the development of many new models and remodels in the country every year, it is extremely unrealistic and unrealistic to collect the load data for each model from the perspective of the development process. A test method that can quickly evaluate products under development, HSRC will bring customers two most important benefits - valuable development time and early test results. Mastering technologies such as HSRC and FTire tire modeling and virtual test field will undoubtedly further enhance the company's technological leadership in the field of structural durability testing.

HSRC technology is an emerging technology that combines the FTire tire model and the digital road surface of the virtual proving ground. Once the HSRC technology is widely recognized and applied, it will inevitably increase the customer's demand for FTire tire modeling applications. At the same time, this technology will also drive the real and virtual road customer dependence on the virtual proving ground that has been built in the Yancheng; In terms of simulation, it can provide customers with more options for structural durability testing solutions. In addition to the existing traditional road simulation solutions based on load load acquisition, it is also difficult to complete the load data in a short time due to factors such as design changes and configuration changes.

## 5. Road simulation test technology of active suspension

Automobile suspension system is an important subsystem of automobile, and it is the main object of automobile test structure durability. The traditional suspension system is mainly composed of shock absorbers, elastic elements, guiding mechanisms, etc., among which shock absorbers are the key components. At present, most models on the market are equipped with a shock absorber with a fixed cross-sectional area of the internal pores, and its damping cannot be adjusted, which is generally called a passive shock absorber.

With people's pursuit of car comfort and handling stability, the electronic control system of shock absorber with active damping is coming out. The overall adjustment idea of the electronic control system is to judge the motion state of the vehicle through the built-in acceleration and other sensors of the vehicle and acheive damping adjustment.

The transition from passive shock absorbers to active damping shock absorbers has greatly improved the vehicle performance, but at the same time, a new test is put forward for the road simulation test method of the structural durability of vehicles equipped with active damping shock absorbers. In the road simulation test of vehicle structure durability based on traditional passive shock absorbers, the characteristics of passive shock absorbers are certain, and the test method focuses on how to make the vehicle's force state and motion attitude converge. After the introduction of the adjustable shock absorber, the stress state of the vehicle and the height of the motion attitude are strongly related to the characteristics of the active damping shock absorber, and the characteristics of the active damping shock absorber are highly dependent on the motion attitude of the car, including the height sensor, vehicle body acceleration, vehicle speed, and torque of the rotating shaft. Therefore, to ensure the convergence of the vehicle's stress state and motion posture, it is necessary to reproduce the characteristics of the active damping shock absorber at the same time. In addition, due to the introduction of adjustable dampers, the nonlinearity of the system composed of test vehicles, benches, sensors, etc. is stronger, resulting in large changes in the frequency response function of the system, further aggravating the difficulty of testing.

At present, there are roughly two methods in the industry for the road simulation test of the durability of automobile structures equipped with active damping shock absorbers. The first type: Specify the characteristics of the active damping shock absorber. At this time, the active damping shock absorber is treated as a passive shock absorber. High performance cannot be fully verified, and the test results are very different from the actual expected results. The second: testing based on hardware-in-the-loop. The physical vehicle system interacts with the dSpace vehicle simulation system, and sends the vehicle motion signal to the vehicle controller. The vehicle controller outputs current to the shock absorber according to the programmed control strategy, thereby realizing adjustable damping. In this test method, a vehicle model needs to be established in dSpace, and the vehicle model needs to have a series of parameters including K characteristics consistent with the test vehicle, and the accuracy is difficult to guarantee, which makes it difficult to guarantee the test accuracy; on the other hand, at present, the complete vehicle controllers configured in domestic vehicles are all developed abroad, and it is difficult to obtain core technologies such as control strategies. In the process of building hardware-in-the-loop, it is difficult to accurately grasp the interface definition, input and output relationship, etc., which leads to the test method has great uncertainty; in addition, what is more important is the huge cost of this test method, the high investment time cost, and the impractical engineering application. Due to the huge cost and uncertain test results, this kind of test method mainly stays in theory or simple attempt at present.

## 6. Conclusions

As people pay more attention to the durability of vehicle structures, relevant testing technologies have been continuously researched, and the accuracy and scope of spindle-coupled road simulation tests have continued to improve. Eventually, the proving ground will be “moved into” the laboratory, spindle-coupled road simulation tests will become the most effective test ways in the development stage of automobile durability.

## References


*[1] Z. S. Liu, F. X. Huo, L. F. Yang, C. M. Wang, and F. Shi, Research on method of vehicle durability bench test based on road profile input [J]. Automotive Technology, 2010(9): 47-50.*

*[2] L. G. Liu, “Load prediction based on virtual pavement” [J]. Shanghai Auto, 2015(1): 22-27.*

*[3] L. F, W. B. Chen, and L. G. Liu, “A bench test method for suspension durability based on virtual load” [J]. Automotive Engineering, 2019, 41(9): 1080-1087.*

*[4] Q. G. Cai, X. Liu, S. X. Bi, and Q. Dai, “Suspension durability development of a passenger car based on virtual random spectrum” [J]. Automobile Parts, 2020(10) :24-28.*

*[5] S. G. Wan, X. K. Zhu, and L. Fan, “FRF optimization of suspension test based on virtual load” [J]. Control Engineering of China, 2021, 28(5): 891-897.*