Technium Electro
Technium Electro Vol. 2, pp.10-25 (2023)
ISSN:3008-6795
www.techniumscience.com

Remote test bench system design course of electric vehicle road resistance simulation for high education

Caizhi Zhang

School of Automotive Engineering; The State Key Laboratory of Mechanical Transmissions; Chongqing Automotive Collaborative Innovation Centre, Chongqing University, Chongqing, China, 400044
Corresponding Authors, Caizhi Zhang, E-mail: czzhang@cqu.edu.cn;

Dongjun Li

School of Automotive Engineering; The State Key Laboratory of Mechanical Transmissions; Chongqing Automotive Collaborative Innovation Centre, Chongqing University, Chongqing, China, 400044

Yuxin Zhang

College of Material Science and Engineering, Chongqing University, Chongqing 400044, P.R. China
Yuxin Zhang, zhangyuxin@cqu.edu.cn

Zaiqiang Meng

China Automotive Engineering Research Institute Co., Ltd, Chongqing, China, 401122

Yi Wang
China Automotive Engineering Research Institute Co., Ltd, Chongqing, China, 401122

Abstract. As an independent curriculum design course, this paper proposes a new remote teaching approach to reinforce students' ability of combination of theory knowledge and engineering practice by a comprehensive test bench system design. This method is useful during the Coronavirus disease (COVID-19) epidemic where stricter social distancing measure is enforced by local government. The design of this test bench system includes two parts, the hardware structure and the system software，which combine the knowledge of fuel cell, automobile and mechanical design, and integrate LabVIEW programming. The transmission structure of test bench is selected to develop the curriculum design course, which is the foundation for mastering the structure and driveline of vehicle. In addition, a road resistance simulation system which adopts a half-duplex RS-232 bus type communication network and accumulate and check-up communication algorithm is realized by LabVIEW. Data communication and control is an important part of the future development of unmanned vehicle. The design process of software and hardware matching is conducive to shaping students' overall understanding of automobile system and to strengthen their ability to apply 3D modeling, simulation and analysis. At last, the questionnaire analysis showed that the proposed remote practical course design method is useful and advisable.

Keywords. electric vehicle; test bench experiment; transmission system; road resistance simulation; remote practice.

1. Introduction

In colleges and universities, the traditional teaching mode is mainly the combination of theoretical courses and a certain degree of practical courses, relying on face-to-face teaching in the laboratory [1]. Students majoring in automotive engineering report they usually prefer to take difficult or important courses face-to-face instead of online [2]. However, during the period of new COVID-2019 epidemic, the highly practical automotive specialty is facing unprecedented challenges and needs new methods to educate in major of automotive engineering without face-to-face teaching.

In addition, with the acceleration of the process of automobile industry transformation, new technologies in various automobile fields emerge one after another, which makes it more difficult to train students majoring in automobile [3,4]. For example, FCVs have captured increasing attention of both government and researches due to pollution-free discharge, high energy efficiency and reduction of greenhouse gas emissions in recent years [5, 6]. Toyota, Hyundai, and Honda have manufactured and sold fuel cell vehicles, such as Mirai, Nexo and Clarity. In addition, as the automobile major itself is a multidisciplinary major, covering many disciplines such as machinery, electronics, energy, intelligence, etc. [7]. However, the current teaching courses in major of automotive engineering carried out all alone, which means that students learn a lot of theoretical knowledge, but not combine them into practice, especially with so many new technologies [8]. Therefore, students majoring in automobiles have limited understanding of automotive engineering and new technologies like fuel cell.

The above factors greatly increase the difficulty of the cultivation of basic knowledge, comprehensive ability and professional quality of students majoring in automobile. Therefore, during the period of new COVID-2019 epidemic, in view of rapid development of technologies on new energy vehicles [5,6,9,10], this paper expounds how to realize the remote design of the test bench [11-18] with knowledge of automobile field, mechanical design, serial port communication and LABVIEW programming as a project supporting student's independent design practice, which will strengthen the practical links of student learning.

This article discussed the course design process of an electric test bench, through emphatically explores problems of mechanical hardware part including the transmission part selection, parts and system safety reliability problem, and software part consists of data acquisition, mathematical model and real-time control, which is beneficial to complete the design of the road resistance simulation test bench. In particular, three-dimensional modeling software like SolidWorks and knowledge of car chassis structure are applied to transmission system model building. Security check and reliability analysis of transmission system and components are accomplished by Ansys and safety check formula. In addition, virtual instrument software is used to develop a road resistance system which combines data acquisition automatically, data process, waveform display, control signal output and data preservation. Finally, the paper investigated the feasibility of remote implementation of the project during the epidemic and its effect on the cultivation of comprehensive practical capacity, which proved to be effective.

2. Teaching Method

This practical design course is carried out for students with knowledge of automobile construction, automobile theory, mechanical design, theory of electric vehicle and serial communication to reinforce practical ability.

In a fuel cell vehicle, the electricity generated by fuel cells and lithium batteries is fed into a motor and converted into mechanical energy, which is then transferred step by step through a mechanical connection to a reducer, transmission shaft axle, main reducing gear, differential mechanism, axle and wheel. According to the automobile theory, road resistance generated during a vehicle driving on the road, which consists of four parts: rolling resistance F_f, air resistance F_w, climbing resistance F_i and acceleration resistance F_j.

$$\sum F = F_f + F_w + F_i + F_j \tag{1}$$

And the generated road resistance is equal to the driving force generated by the motor.

Figure 1 shows schematic diagram of vehicle road resistance simulation system, which presents the working principle of the test bench. A road resistance simulation system is consisted of mechanical transmission system, data acquisition and control system. During the design process of mechanical transmission system, the driving mechanism, transmission components, sensors and dynamometer need to be selected and modeled refer to the chassis structure of electric vehicle, calculation of automotive driving formula and mechanical design. In addition, the design of the data acquisition and control system requires serial communication knowledge, the conversion between rotational speed and vehicle velocity, the model of road resistance of vehicle driving, knowledge of data format conversion, etc. What follows is a guide to design work that helps students understand, model, program, validate, and design the practical course. The main practical goal is to establish safe and reliable parts and assembly models according to the requirements and relevant parameters, and to use LabVIEW to write the road resistance simulation program, so as to realize the design of the road resistance platform of electric vehicles.

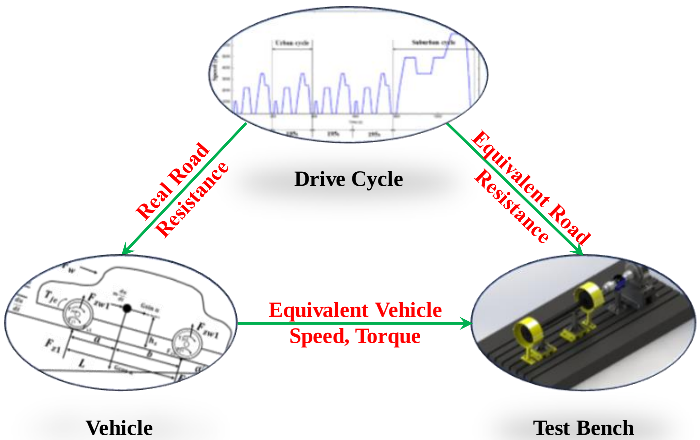


Fig. 1. Schematic diagram of vehicle road resistance simulation system

3. Transmission system design

3.1. The mechanism framework of the test bench

The design of the transmission system will help students to systematically look at the structure, function and working conditions of the transmission system. In this paper, the forward construction scheme is adopted. As shown from figure 2, the rear axle (actually the motor) acts as power train. Then, the sensor and the actuator use a torque-speed transducer and a magnetic powder brake respectively. In addition, the intermediate transmission mechanism of the system is constituted by the flange shaft sleeve, the transition connecting shaft and elastic coupling. Finally, support of main transmission components and reliable fastening of test bench system are realized by adjustable pedestals and the base frame.

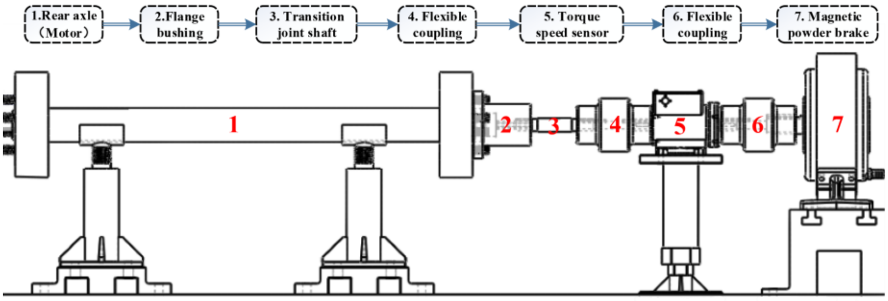


Fig. 2. Overall design of forward horizontal construction scheme

Among them, motor, reducer and the half shaft wheel hub are a connected unit taken from an electric tricycle. The motor and the reducer are hidden because they are not on the same axis. In addition to the power source, the Torque-Speed Transducer and the Magnetic Powder Brake are regarded as the dynamometer which realize functions of torque and speed measurement and torque applied. In addition, adjustable pedestals specially designed and can be fine-tuned in XYZ direction are used to support those transmission parts reliably. The base frame of the test bench is placed at the bottom to support all components and maintain horizontal stability.

3.2. Test bench installation datum

For rotary security and reliability of rotary type test bench, the datum determination of transmission axis and the surface of mounting base crucial. The set of installation datum should meet the requirements of coaxiality accuracy and easy arrangement of the components.

Table 1: Size of transmission parts of test bench

Transmission Parameter	Symbol	Value[mm]
Radius of motor	R_m	130.0
Radius of half shaft	R_{HS}	30.0
Radius of wheel hub	R_{WB}	95.0
Max Radius of flange shaft sleeve	R_{FSS}	60.0
Height of transducer	H_{TST}	55.0
Radius of coupling	R_C	46.5
Height of the magnetic powder brake	H_{MPD}	155.0

Size of transmission parts of test bench are shown in table 1, the magnetic powder brake has

Technium Electro Vol. 2, pp.10-25 (2023)
ISSN:3008-6795
www.techniumscience.com

the maximum height H_{MPD}. Combined the design height of adjustable pedestals, this paper finally set the axis datum at the position of 300mm. This height ensures adjustable pedestals can be arranged suitable and achieve these functions.

3.3. System components selection and modelling

According to those structures and parameters of the rear axle, the torque-speed transducer and the magnetic powder brake, refer to design requirements of <Machine Design>, connectors such as flange-coupling, transition shaft and elastic coupling are designed and modeled. The models of transmission system and transmission components are shown in figure 3. After the picture, the parameter properties of each transmission part are introduced.

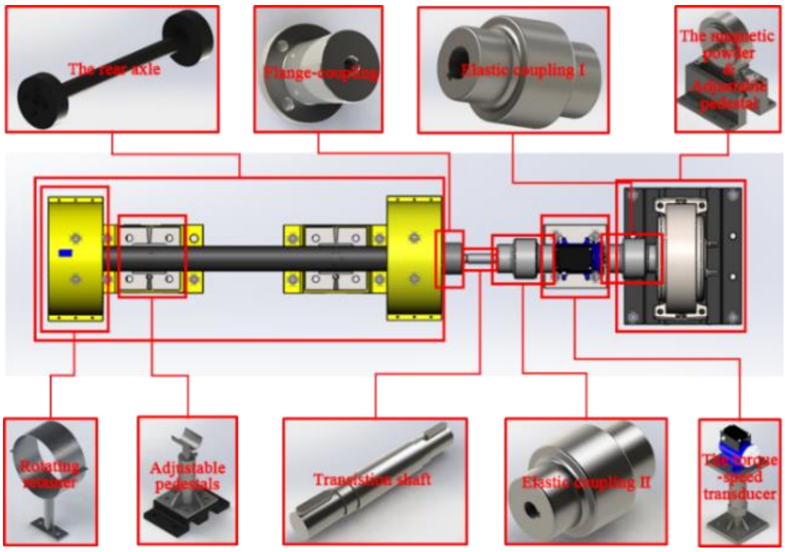


Fig. 3. Models of the transmission system and transmission components

3.3.1. Motor

In this paper, the drive device is from an electric tricycle. The motor is a reluctance motor, which is decelerated by a reducer, and finally output to the hub through the rear axle. The torque and speed calculation formula of motor and reducer T_{mot}, T_{red} and n_{red} is given by:

$$P_{mot} = \frac{\pi T_{mot} n_{mot}}{30 \times 1000} \tag{2}$$

$$T_{red} = \frac{9550 P_{mot} i_0}{n_{mot}} \tag{3}$$

$$i_0 = \frac{n_{mot}}{n_{red}} \tag{4}$$

According to engineering practice, the locked-rotor torque is 2~3 times of the rated torque of the transmission system, so the locked-rotor torque is given by:

$$T_{Loc} = (2\sim3) \times T_{max} \tag{5}$$

The torque range of the magnetic powder brake depends on the value of the locked-rotor torque. Finally, the main parameters of the drive device are shown in Table 2.

Table 2: Parameters of the drive device.

Parameters	Symbols	Unit	Value
Rated power	P_{mot}	W	1200
Ratio	i_0	-	15.5:1
Motor speed	n_{mot}	rpm	6900
Reducer speed	n_{red}	rpm	445
Motor torque	T_{mot}	N · m	1.6
Reducer torque	T_{red}	N · m	25.575
Locked-rotor torque	T_{Loc}	N · m	51.15~76.725

3.3.2. Dynamometer

According to the output range of the driving device showing in Table 2, both the torque-speed transducer (ZJ-100A) and the magnetic powder brake (CZ-100) produced in Jiangsu LanLing Company are selected. The torque applied range of the magnetic powder brake and the allowable torque range of the transducer are *0~100N • m*. In addition, the transducer speed and torque measurement range are *0~6000rpm* and *0~100 N • m*, respectively.

The dynamometer made up of the brake and the transducer provides resistance loading function refer to the measured driving state. Figure 4 shows a good linear relationship between the excitation current and the output torque of the magnetic powder brake, which simplifies control model. Therefore, the magnetic powder brake generates the braking torque by magnetic current in the excitation coil, so as to simulate the driving resistance of vehicles.

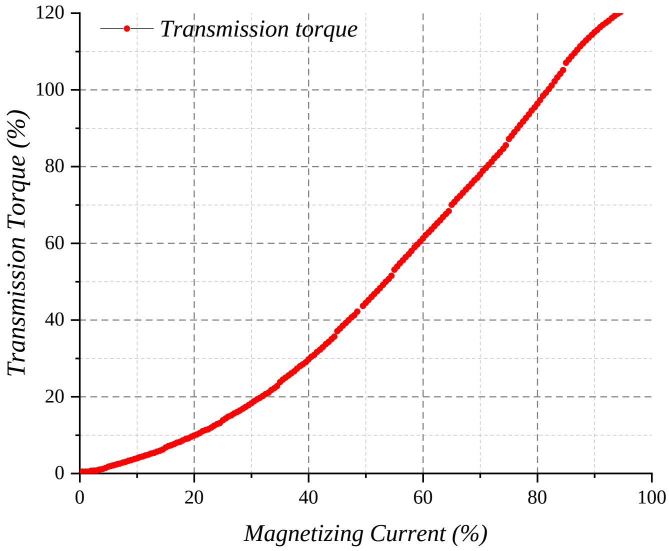


Fig. 4. Relationship between magnetizing current and transmission torque of the Magnetic Powder Brake (CZ-100)

3.3.3. Elastic coupling

The usage of elastic coupling makes sure the transmission system closely connected and can withstand certain radial impact. Therefore, according to the diameter of the shaft, the type and size of the flat key on the shaft, models for star elastic coupling ($XL6 - \phi50/\phi45$) was chosen for the transducer connected with the transition shaft and the magnetic powder brake. Its two-end connection journal is 18mm and 30mm respectively, through A flat key for transmission.

3.3.4. Flange-coupling

Because the motor, reducer and the half shaft wheel hub are integrated, the power is output through the hub. Therefore, in order to transmit the power from the motor, the flange-coupling was designed particularly according to the structure of the wheel hub which has four evenly circumferential bolts. Therefore, the flange-coupling is connected with the shaft through the shaft hole to output power to the transition shaft.

3.3.5. Transition shaft

The transition shaft was designed to connect the elastic coupling and the flange-coupling, which avoids the rigid connection between flange-coupling and the torque-speed transducer. Table 3 shows the basic parameters of the transmission shaft.

Table 3 Specification of the transition shaft

Parameter	Symbol	Unit	Value
Allowable twisting stress of 45 steel	$[\tau_T]$	Mpa	45
Flat key-height	h	mm	6
Bond length of flat key	L	mm	25
The working length of the flat key	l	mm	19
Diameter of the shaft	d	mm	18
Flat key-width	b	mm	6
Connection transmission torque	P	N · m	25.575
Extrusion stress of 45 steel	$[\sigma_p]$	Mpa	50

Considering the transition shaft is only subjected to torque, the minimum diameter of the shaft is estimated based on the torsional strength condition. The diameter d_{min} is given by:

$$d_{min} = \sqrt[3]{\frac{9550000\frac{P_{mot}}{n_{mot}}}{0.2[\tau_T]}} \tag{6}$$

After calculation, the minimum diameter of the shaft d_{min} is 14.09mm. Since the axle journal of torque-speed transducer is 18mm, so the minimum axle journal of the transition shaft is set as 18mm. That's design not only meets the requirements, but also makes the selection of elastic coupling easier.

The two ends of the shaft are connected with the elastic coupling by symmetrical A-type flat keys. According to the calculation result of the flat key strength calculation formulas (7) and (8), it shows the security requirements are meted.

$$l = L - b \tag{7}$$

$$\sigma_p = \frac{4000T}{hld} = 49.854Mpa \le [\sigma_p] \tag{8}$$

3.3.6. Base frame of test bench

The base frame of the whole system which weighs 2.52 t is made of 2000mm×1000mm×160mm cast iron. The base frame has inverted T-slot, which fastened with pedestals by T-head bolt.

3.3.7. Adjustable pedestal

In order to keep the transmission parts on the same datum axis, the adjustable pedestals referred to the inverted T-slot were designed. The structural combination of adjustable pedestals with base frame and transmission components made it possible the rear axle, the torque-speed transducer and the magnetic powder brake can be fine-tuned in XYZ direction.

As shown in figure 5, the adjustable pedestals and transmission components are arranged like that. The principle of position adjustable is as follows. Above all, the connection of the inverted T-slot and the T-head bolt made all transmission components can be adjusted in the Y direction. In addition, the combination of the lead screw and the locking nut help the rear axle and the torque-speed transducer adjust in the Z direction. At last, in the X direction, the pedestal of the magnetic powder brake has inverted T-slot. The torque-speed transducer and the pedestal of the rear axle have a connection hole shaped like A-type flat key, which made the bolts can be fine-tuned in the X direction.

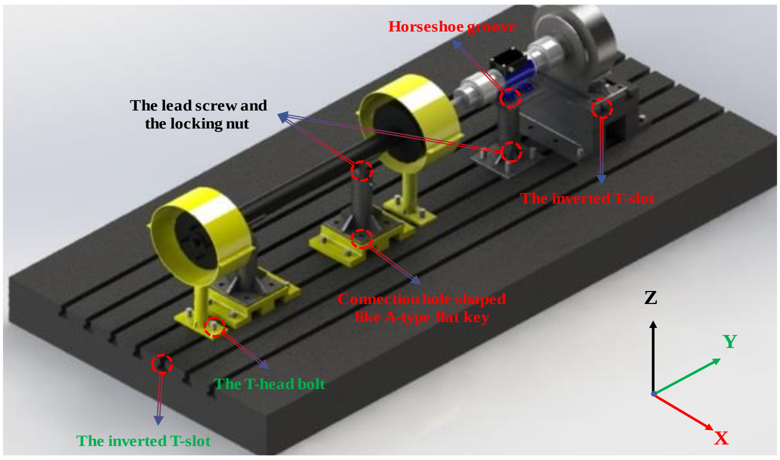


Fig. 5. Adjustable components arrangement in test bench

3.3.8. Rotating retainer

Basically, the maximum rotational speed of this system can reach 645rpm (n_{red}). Therefore, the rotating retainer was arranged on the periphery of large rotary parts to ensure the personal safety of the staff.

3.4. Security check of non-stand components

Some non-standard components such as flange-coupling, adjustable pedestals for rear axle and the magnetic powder brake are designed to be used in the test bench. In order to verify its safety during operation, the transmission components were checked by Ansys simulation.

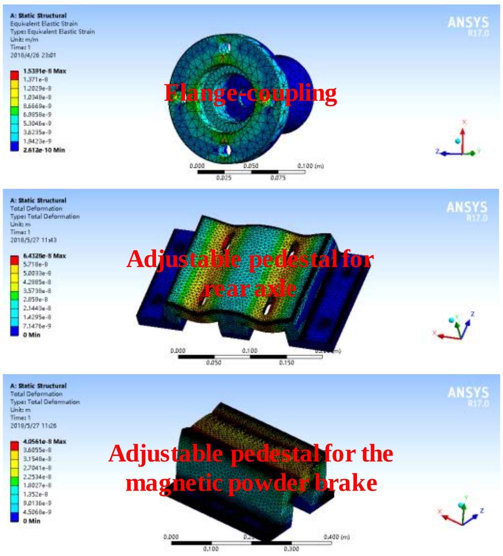


Fig. 6. Ansys analysis results of non-standard components

The simulation is performed by setting the actual required torque range or pressure change in Ansys. Figure 6 shows the simulation results which reflect the fact that the strength and stiffness of those components are fully met. In detail, the mises stress and mises strain of the flange-coupling are 3.19Kpa and 1.539×e^ (-8) m. In addition, the total deformation of the adjustable pedestal of rear axle is 0.06432μm, which is almost negligible, the same as the adjustable pedestal of the magnetic powder brake.

4. Road resistance simulation system design

4.1. Road resistance simulation system structure

The design of road resistance simulation system needs to analyze the properties of mechanical transmission system and required functions. In this paper, the main function of road resistance simulation system is torque signal control in sync to simulate road resistance. In particular, functions of data collection, data display, waveform display and so on need to be realized, which means students participating in the project need to combine their knowledge of half duplex communication, LabVIEW programming and road resistance model based on automotive driving formula.

Figure 7 shows the framework of the road resistance simulation system composed by hardware and software. The hardware structure contains the torque-speed transducer, an acquisition system, a computer with test software, a controller and the magnetic powder brake. In addition, the functions of the software mainly contain of data input, data processing, data storage and data output.

Technium Electro Vol. 2, pp.10-25 (2023)
ISSN:3008-6795
www.techniumscience.com

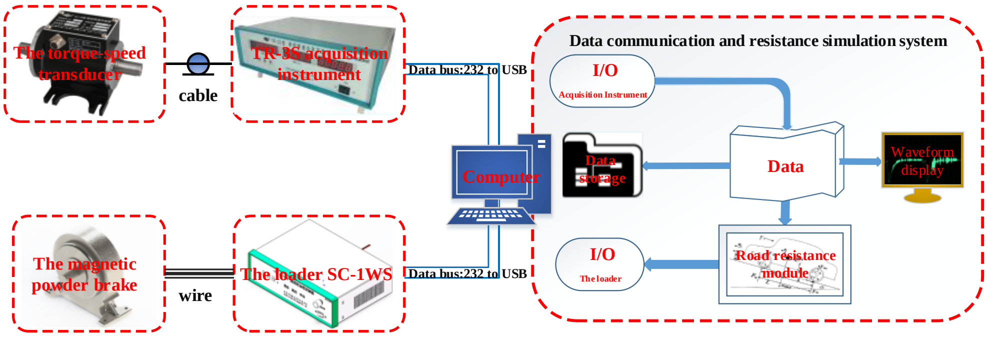


Fig. 7. Road resistance simulation system architecture

4.2. Software achievement and methods

Simple interactive interface and fast data synchronization are the core of road resistance communication system. Based on this requirement, LabVIEW, which integrates interactive interface design and programming, was selected to implement the road resistance communication simulation system.

Figure 8 shows the finished software interactive interface which includes 4 parts. I/O serial communication selection zone is used to communicate with the TR-3S acquisition instrument and the SC-1WS programed loader. And the test initial parameter setting zone is used to set vehicle basic parameters and simulated road environment parameters before testing. At last, the waveform display zone and numerical display zone features real-time display of torque, speed, road resistance and converted speed and other information.

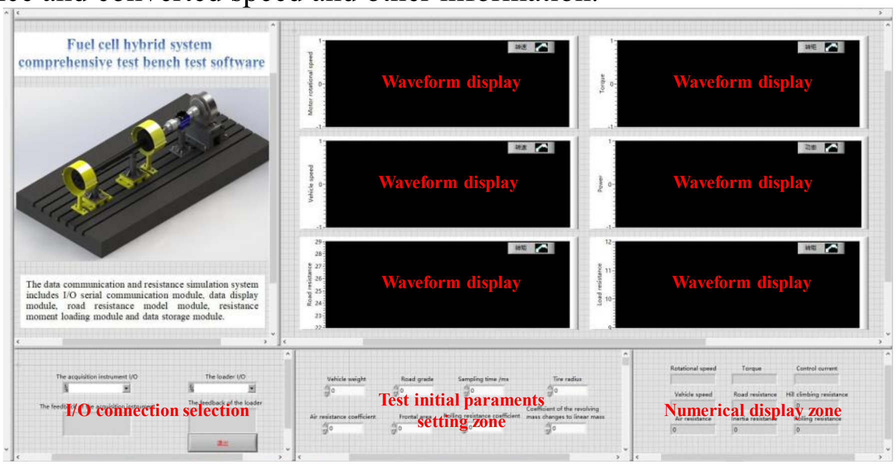


Fig. 8. Data communication and control system test interface

And figure 9 shows the general control flow of the system. Prior to the start of the test, vehicle parameters and road conditions were entered into the test initial paraments setting zone. After that, when the test bench system operates, motor, reducer and the rear axle etc. gradually rotate, test software starts to simulate and record. The acquisition instrument TR-3S collects the data, and then sends it to the host computer. On the one hand, the system displays received speed and torque signal and other processed data like several road resistance in real time. On the other hand, the torque control signal is sent to the program-controlled loader to simulate the real-time road resistance condition. Finally, test data is saved as an Excel file.

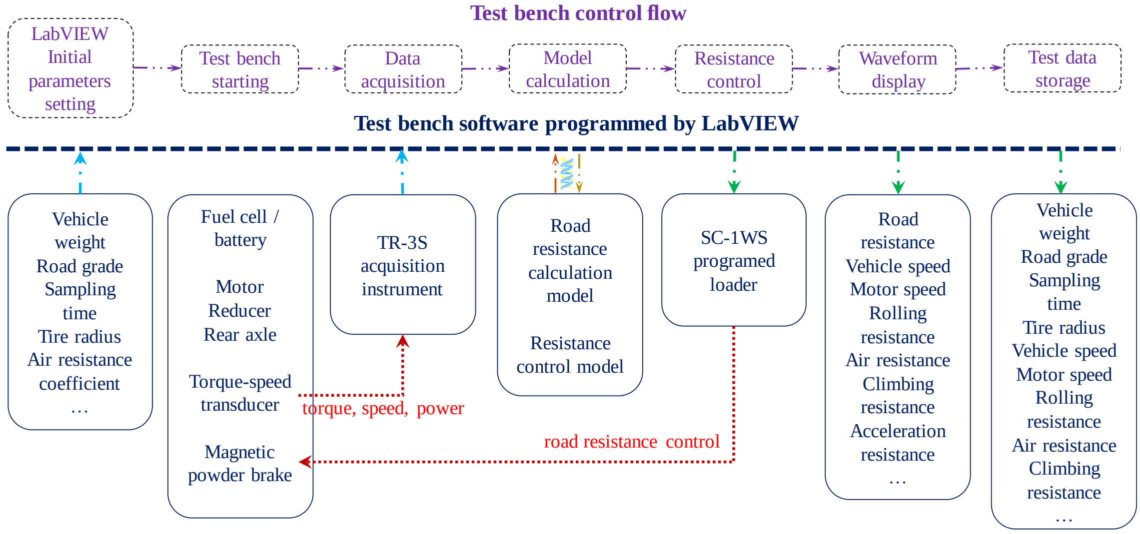


Fig. 9. Test bench system control flow

In order to realize the above functions, the background code block diagram is composed of 5 modules, I/O serial communication module, data display module, road resistance model module, resistance moment loading module and data storage module. These modules are designed independently, but they are interrelated in function implementation. Figure 10 shows the data flow between modules. And the five modules are described below.

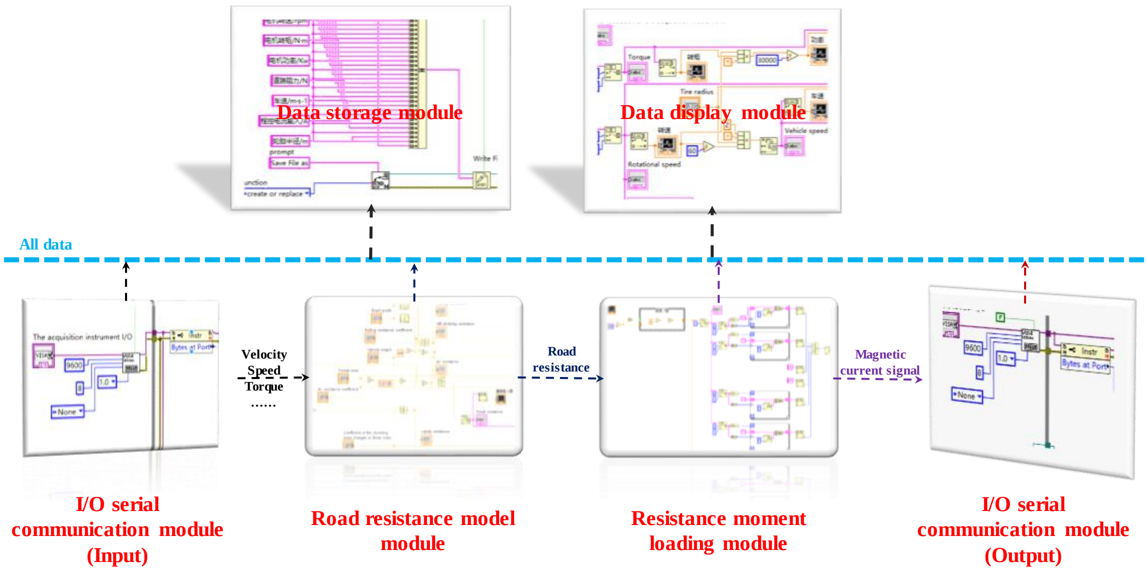


Fig. 10. Data flow between modules

4.2.1. I/O serial communication module

In this paper, the system adopts a half-duplex RS-232 bus type communication network and accumulate and check-up communication algorithm, which are carried on data transmission. According to the equipment serial port communication baud rate (9600), data bit (8) and other information, VISA module is used in LabVIEW to receive and send the signal which way of transmission format is Modbus to the acquisition instrument and the program-controlled loader.

4.2.2. Data display module

The data sent by the acquisition instrument is the ASCII code of decimal number in LabVIEW. The data frame format is the address command, torque and speed message, cumulants, factory number and data tail. Therefore, after identifying the string information, the torque and speed message are intercepted and extracted automatically by string truncation module. In addition, in order to display rotational speed and other information, ASCII code should be converted into double-precision floating points and sent to the waveform module.

4.2.3. Road resistance model module

According to the vehicle driving formula and vehicle parameters, road resistance model module is built to respond and simulate the change of road resistance caused by the change of motor speed. The vehicle driving formulas and specification are shown below.

$$\sum F = F_f + F_w + F_i + F_j \tag{1}$$

$$F_t = \frac{T_m i_0 \eta_T}{r} \tag{9}$$

$$F_f = mgfcos\alpha \tag{10}$$

$$F_f = mgfcos\alpha \tag{11}$$

$$F_i = mgsin\alpha \tag{12}$$

$$F_w = \frac{C_D A u_a^2}{21.15} \tag{13}$$

$$F_j = \delta m \frac{du_a}{dt} \tag{14}$$

Table 4 shows specification of an electric vehicle produced in Reech Auto Group. In addition, the vehicle velocity u_a can be calculated as:

$$u_a = 2\pi r n_{mot} / 60 i_0 \tag{15}$$

Combined with the formula 1, 9-14 and specification of an electric vehicle showed in table 4, a real-time change in road resistance is programmed in LabVIEW.

Table 4: Specification of an electric vehicle produced in Reech Auto Group.

Parameter	Symbol	Unit	Value
Weight	m	kg	1812
Climbing angle	α	°	0
Air drag coefficient	C_D	-	0.35
Front area	A	m^2	2.604
Correction coefficient of rotating mass	δ	-	1
Rolling resistance coefficient	f	-	0.01003
Tire radius	r	mm	355
Gravitational acceleration	g	-	9.8
Transmission efficiency	η_T	-	95%
Transmission ratio	i_0	-	15.5

4.2.4. Resistance moment loading module

Resistance moment calculated by road resistance model should be applied to the magnetic powder brake by the program loader. Therefore, the conversion relationship between the resistance and the magnetic current (Figure 4), the generation model of control signal of the magnetic current value were programed in LabVIEW. At last, the control signal was transferred into ASCII code to write into the program-controlled loader.

4.2.5. Data storage module

In view of the convenience and requirements of subsequent research and analysis, all test data are converted into double-precision floating points and stored in a new Excel file.

4.3. Validation test of the software

After the design part, a set of NEDC vehicle velocity data replaced the signals measured during the actual test was entered through XCOM and VSPD to verify the functionality of the test software. Figure 11 shows two verification schemes, comparing the current value of the output control signal or the measured current value of the multimeter with the current value calculated by the software. The reliability of the software, such as real-time serial port communication, data storage, model calculation and so on, is verified by this method.

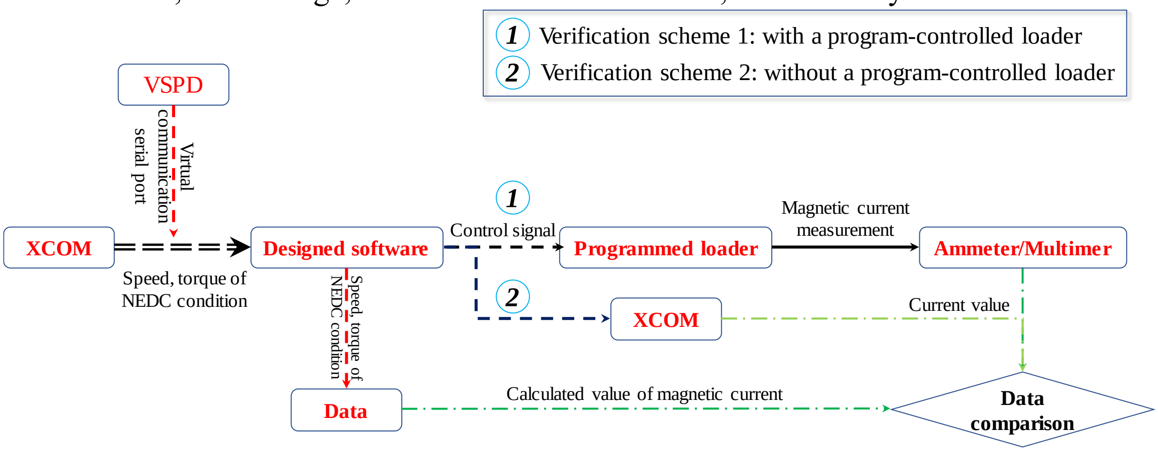
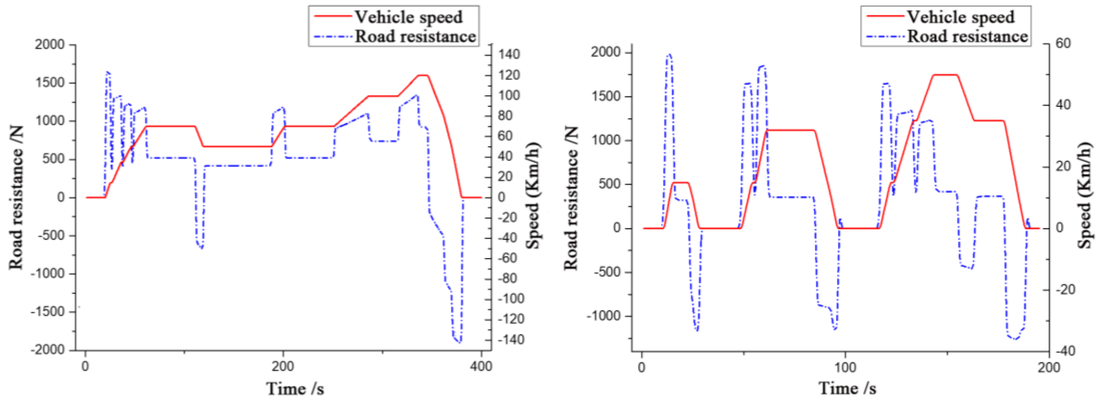


Fig. 11. Two verification schemes of the software

Vehicle parameters in Table 4 was selected as the initial parameters to input the system, figure 12 shows road resistance change obtained by the software at NEDC condition.



(a) (b)

Fig. 12. Changes in road resistance and velocity over time (a) urban cycle (b) suburban cycle

5. Discussion of course evaluation

The effectiveness of this remote course design method was evaluated by the participants of this independent course design project. Table 5 shows the summarized survey results from 107 participants in 2020. In general, this practice course was rated positively by participants (83.18% rated "Good enough" and 16.82% rated "Improvement needed"). The survey results clearly indicated that this practice course has a good feasibility and teaching effect during COVID-2019.

Table 5: Analysis of the course evaluation survey

No	Survey Questions	Response		
1.	Is it advisable to conduct the course practice of cultivate practical ability through remote operation during COVID-2019?	Satisfactorily 90.65%	Ordinarily 5.61%	Inadequately 3.74%
2.	How do you like the feasibility of this design practice of mechanical part?	High 71.96%	Medium 22.43%	Low 5.61%
3.	How do you like the feasibility of this practice course of programing part?	High 69.16%	Medium 24.30%	Low 6.54%
4.	Can this practice course under remote operation help you master the curriculum knowledge to practice effectively?	Yes 97.2%	No 2.8%	
5.	Does this kind of course fulfill the needs of practical teaching?	Excellent 74.77%	Good 24.30%	Fair 0.93%

In view of the survey results, most participants agree that the course can help them improve their practical ability. Therefore, 5 participants and 5 non-participants of the practical course were interviewed. The comparison results show that in terms of automotive powertrain, participants can systematically and in more detail express the main indicators of powertrain performance test and the role of each transmission in the powertrain. At the same time, when it comes to sensor signal communication, participants not only pay attention to the type of signal, but also pay more attention to signal delay, signal acquisition frequency and other aspects. This indicates that the curriculum practice of this platform builds a bridge between students' theoretical knowledge and engineering, and constructs a framework of knowledge that includes all important details. Therefore, the new remote practice course of test bench system design for college is highly recommended in the periods of major public incidents.

6. Conclusion

When public emergency circumstances occur such as COVID-2019 epidemic, the teaching approach in Institute of Higher Education must transform to meet the challenges in strict social distancing measure. That often brings several challenges to the course practice that is required to conduct in laboratory. In this paper, a course design method that can be operated remotely to train students to integrate theoretical knowledge and improve their practical ability has been proposed. According to the data and data provided, the practice of three-dimensional modeling and LabVIEW programming in the bench design can be accomplished remotely.

The design of road resistance simulation test bench is conducive to students understand driveline and data communication of electric vehicle systematically. The design of this independent curriculum project can improve the students' ability to comprehensively use the curriculum knowledge (e.g., automobile theory, fuel cell foundation, computer network communication and mechanical design, etc.) and improve their engineering practice ability under public emergency circumstances.

7. Acknowledgement

This work is supported in part by the national key research and development program (No.: 2018YFB0105402), the Chongqing Research Program of technological Innovation and application (No.: cstc2019jscx-fxyd0158, cstc2018jszx-cyztzxX0005), and the Fundamental Research Funds for the Central Universities (No.: 244005202014, No.: cquyjg19205, No.: yjg193009 and No.: 2019CDXYQC0003).

References

[1] Li Xiaojuan, Guan Yong, Yuan Huimei. Curriculum Development and Progressive Engineering Practice Design in Embed System Education[C]// IEEE/ASME International Conference on Mechtronic & Embedded Systems & Applications. IEEE, 2008.

[2] Martínez, P. J., Aguilar, F. J., & Ortiz, M. (2019). Transitioning From Face-to-Face to Blended and Full Online Learning Engineering Master's Program. IEEE Transactions on Education.

[3] TRAUB M, MAIER A, BARBEHON K L J I S. Future Automotive Architecture and the Impact of IT Trends [J]. 34(3): 27-32.

[4] HUSSEIN K, FUJITA A, SATO K. Trend in power devices for electric and hybrid electric vehicles; proceedings of the 2015 20th Asia and South Pacific Design Automation Conference (ASP-DAC), F, 2015 [C].

[5] EBERLE U, MüLLER B, VON HELMOLT R J E, et al. Fuel cell electric vehicles and hydrogen infrastructure: status 2012 [J]. 2012, 5(10): 8780-98.
[6] LUCIA U J R, REVIEWS S E. Overview on fuel cells [J]. 2014, 30(164-9.
[7] XU X, WANG C, LIAO G, et al. Development of a plug-in hybrid electric vehicle educational demonstration unit; proceedings of the 41st North American Power Symposium, F, 2009 [C]. IEEE.
[8] FANG T P, DAUD W R W, HALIM L, et al. How Ready is Renewable Energy? A Review on Renewable Energy and Fuel Cell Teaching in Schools; proceedings of the 2017 7th World Engineering Education Forum (WEEF), F, 2017 [C]. IEEE.
[9] WU Y, ZHANG S, HAO J, et al. On-road vehicle emissions and their control in China: A review and outlook [J]. 2017, 574(332-49.
[10] HERRERA V I, MILO A, GAZTANAGA H, et al. Design and Experimental Comparison of Energy Management Strategies for Hybrid Electric Buses Based on Test-Bench Simulation [J]. 2018, 55(3): 3066-75.
[11] CHEN Y, MELAINA M J T R P D T, ENVIRONMENT. Model-based techno-economic evaluation of fuel cell vehicles considering technology uncertainties [J]. 2019, 74(234-44.
[12] GAO J, LI M, HU Y, et al. Challenges and developments of automotive fuel cell hybrid power system and control [J]. 2019, 62(5): 51201.
[13] SALAH M, ABU MALLOUH M, YOUSSEF M, et al. Hybrid vehicular fuel cell/battery powertrain test bench: design, construction, and performance testing [J]. 2017, 39(9): 1431-40.
[14] YONGCHANG D J T O T C S O A M. Research on iteration algorithm used for vehicle road simulation [J]. 2002, 33(2): 5-7.
[15] DU Y, GUAN D J J O T U. Development of computer measurement and control system for vehicle road simulation system [J] [J]. 2002, 4(
[16] JIAOTONG S J S I C E. Simulation and Experimental Research on Vehicle Engine Road Running Mode [J]. 2000,
[17] KHATUN P, BINGHAM C, SCHOFIELD N, et al. An experimental laboratory bench setup to study electric vehicle antilock braking/traction systems and their control; proceedings of the Proceedings IEEE 56th Vehicular Technology Conference, F, 2002 [C]. IEEE.
[18] ALCALA I, CLAUDIO A, GUERRERO G. Test bench to emulate an electric vehicle through equivalent inertia and machine dc; proceedings of the 2008 11th IEEE International Power Electronics Congress, F, 2008 [C]. IEEE.
[19] DODDS C, PLUMMER A, 0148-7191 [R]: SAE Technical Paper, 2001.
[20] MAOWEI J, JUNWEI T. Experimental research for simulating Motorcycle 'Emission Test Mode'on the Engine Dynamic Test Bed; proceedings of the 2011 International Conference on Electric Information and Control Engineering, F, 2011 [C]. IEEE.
[21] LUO Y, LI S, ZHOU L, et al. The development of dynamic test bench for EV hybrid brake system [J]. 2012,
[22] LIU C J C J U. Control technology and performance research on integrated system of electromagnetic brake and frictional brake of car [D] [J]. 2012,
[23] McInerny S A, Dai Y. Basic vibration signal processing for bearing fault detection[J]. IEEE Transactions on education, 2003, 46(1): 149-156.