The design of a vehicle-mounted test system for the thermal performance of solar collector

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Abstract. To increase the test efficiency of thermal performance of solar collector, a vehicle-mounted test system with high automation, simple operation, good mobility and stability is proposed in this paper. By refitting a medium bus, design of mechanical system and test loop, and using PC control technology, we implemented the vehicle-mounted system and realized effective integration between vehicle and test equipment. A number of tests have been done, and the results show that the vehicle-mounted test system has good parameters and performance and can be widely used to provide door-to-door testing services in the field of solar thermal application.

1. Introduction

Solar collector is the key component of domestic and industrial thermal solar systems，which absorbs solar radiation and converts it into heat and be widely used around the world. Whether the quality of solar collector is good or not, is directly relating to the quality of thermal solar systems. Thermal performance test is most important to evaluate the quality of solar collectors, but the test method is very complex because of the following factors [1]:

- According to GB/T 4271-2007 and ISO 9806: 2013, performance tests (steady-state efficiency, angle modifier, time constant) required for the collector be mounted outdoors where the hemispherical solar irradiance shall be greater than 700w/m^2 [2].
- Temperature and flow of the heat transfer fluid need to be controlled precisely and kept stable at set value.
- The feature of solar collector is big in size, heavy in weight.
- The solar collector belongs to the glass products, sample transport costs are relatively high.

With the haze weather increasing in recent years, effective test days decrease significantly, the existing fixed test equipments are unable to meet the growing test requirements [3]. The vehicle-mounted test system designed in this paper can realize mobile tests in different places; the laboratory can provide a door-to-door service, which is convenient to the clients by improving the test efficiency.

2. System design

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2.1.General design

The general design from initial design to final design has experienced several stages, such as data collection, spot investigation, vehicle selection, scheme discussion, final scheme demonstration and determination.

After taking into account all the requirements such as system functionality, vehicle safety, technical parameters, technology advancement, integral aesthetics and anti-leakage, the final design scheme was determined. The core of its content includes:

- To choose medium bus as the basis of vehicle system and refit to meet the need of design.
- When the vehicle-mounted test system is moving or at non-working state, all devices are fixed inside the vehicle, as show in figure 1.
- When working, a few devices, mainly including the collector tracking frame, automatically be moved out of Vehicle, and then the collector sample will be installed and prepared for testing, as show in figure 2. After the test, the tracking frame will be taken back into Vehicle.

Above all, this design scheme has the following advantages:

- During the test tracking frame is supported on the ground, installing or removing the test sample is more convenient, and that can ensure its high load-bearing capacity and good stability.
- Medium bus has properly payload, moreover, its mobility and flexibility are better than heavy vehicles.

The vehicle-mounted test system consists mainly of five parts: modified vehicle, mobile platform, tracking frameclosed test loop, measurement and control system, etc.

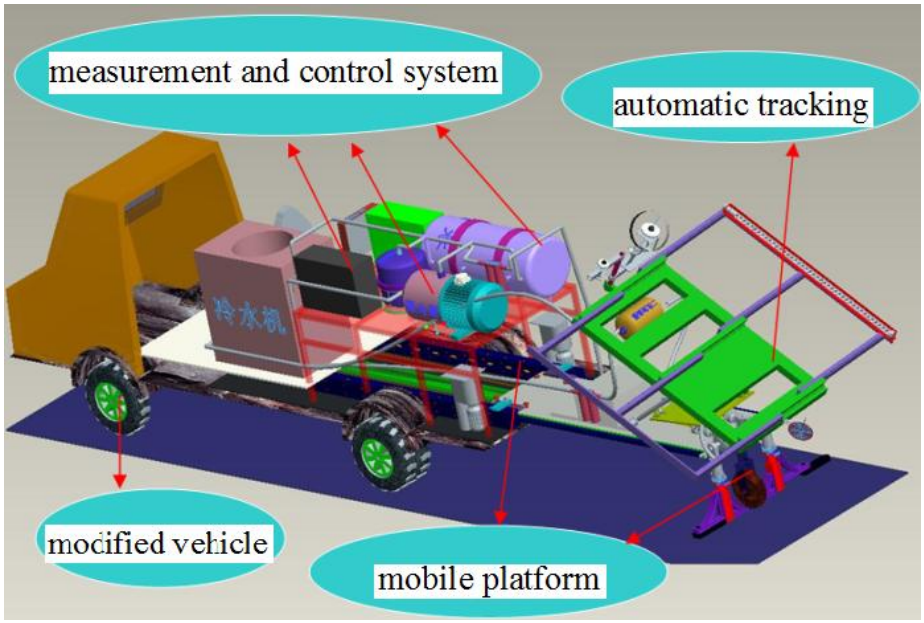

Figure 1. All devices in the vehicle.

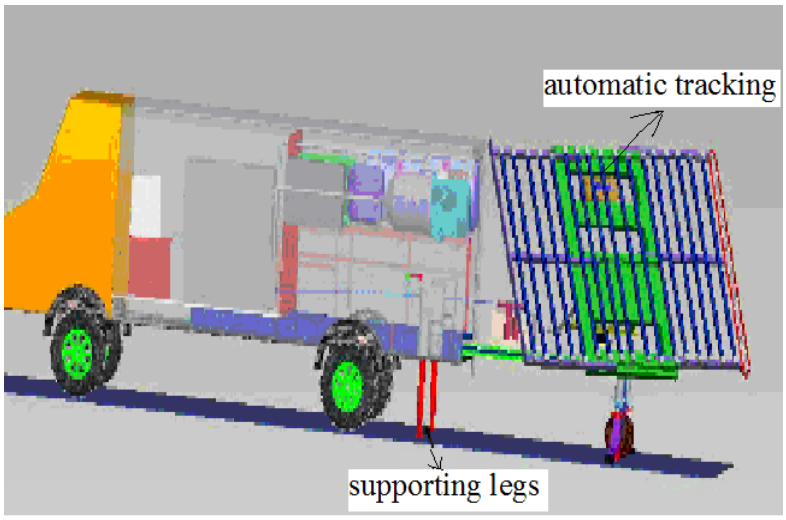

Figure 2. Tracking frame out of the vehicle.

2.2.Vehicle refit

Vehicle is the carrier of the test system. A commercial vehicle was chosen, its parameters are shown in the table 1 below.

Table 1. Parameters of vehicle.

Manufacture	JMC transit
Wagon / Van	Transit Wagon
Engine	Diesel inline, 2.8T
Overall Dimensions (length * Width * Height)	6503*2000*2615（mm）
Roof (Low, Medium, High)	High
Rear wheels	dual
Wheelbase	Long Extended, 3750mm
Maximum Payload	1400 kg
Gross Vehicle Weight	3500kg
Maximum speed	120 km/h

According to system layout and the load requirement, the corresponding refit for the vehicle has been made:

- Interior layout adjustment: remain the driver seat and copilot seat, remove other seats; divide interior space into seat area, operating area and equipment area by detachable clapboards.

- Top refit: The air-conditioning has been installed on the top of the vehicle, whose outlet is in the operating area.
- Bottom refit: in order to support and balance the whole vehicle, at the bottom of the vehicle, the crossbeam has been strengthened and another four electric supporting legs have been added.
- The whole floors of the vehicle have been strengthened.

2.3. Mechanical system design

The mechanical system mainly includes the mobile platform and the collector mounting frame. As the key of the effective integration of the test system and the vehicle, the mobile platform system is responsible for removing and taking back the mounting frame by chain transmission mode. Positioning and fixing have been designed for the mobile platform to ensure the system stability. The collector mounting frame has been designed as a two-axis tracking system[4], can move automatically to follow the sun in azimuth and altitude, the support surface on which can stretch out and draw back automatically for the different sizes of solar collectors, as show in figure 3.

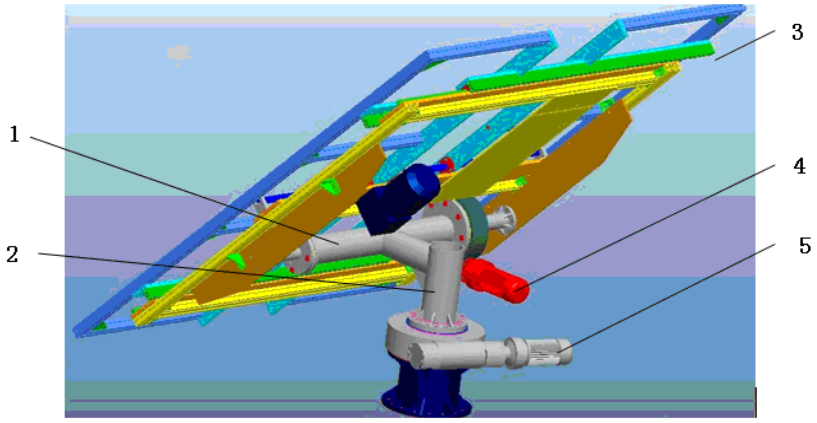

Figure 3. Collector frame using automatic tracking.

1. Altitude angle tracking axis; 2.Azimuth angle tracking axis; 3.Collector supporting surface; 4. Altitude angle motor; 5.Azimuth angle motor

2.4. Design of test loop

The closed test loop [5], based on the closed test loop diagram in ISO 9806-2013 [1]and GB/T 6424-2007, designed for the self-control and self-regulation of the temperature and flow of working fluids, is mainly composed of cooler, the heat insulating water tank, heater, the mixing pump, flow meter, temperature sensors, the pipe, etc.

2.5. Design of measurement and control subsystem

2.5.1. Hardware design

The measurement and control system, based on PC for the data acquisition and electrical control as shown in figure 4, is mainly composed of different kinds of sensors, signal conditioning circuit board, 16 channel 16 bit A/D conversion board, industrial PC, 8 channel 16 bits D/A conversion board, isolated I/O module and the actuators, etc. Data and status of various sensors can be collected in real-time by motion control cards and data acquisition cards, and then used to control the operation of system after program processing and output.

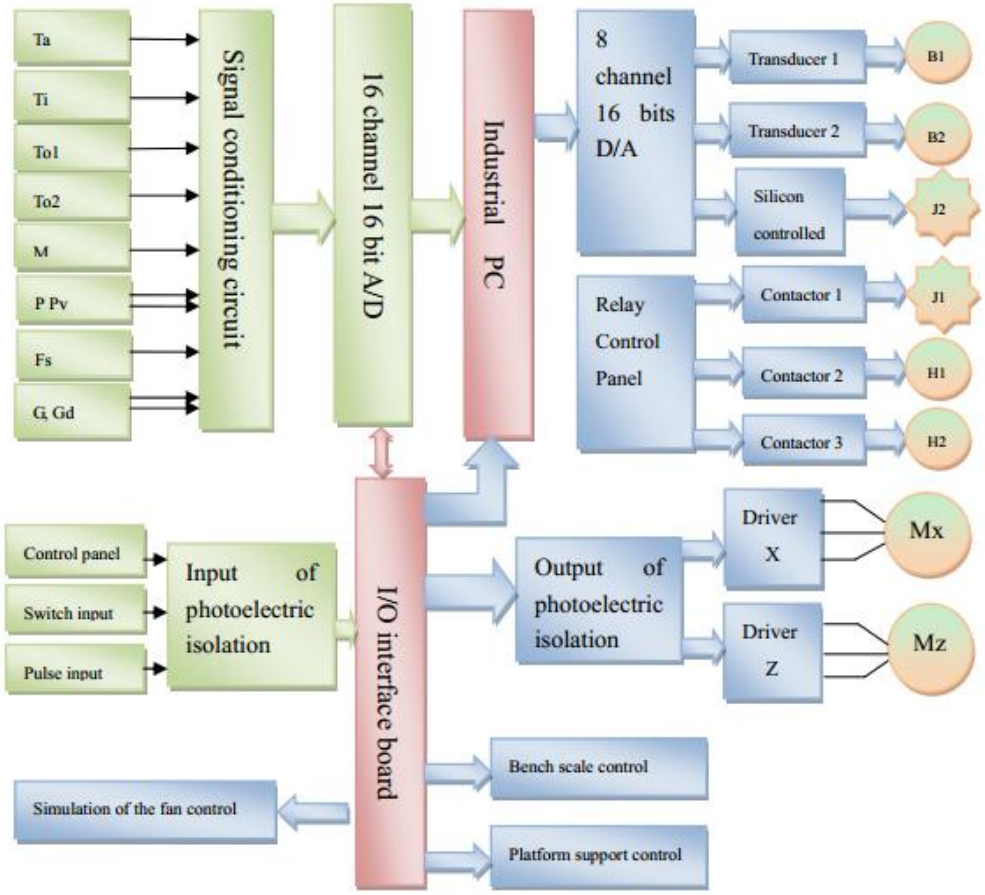

Figure 4. Hardware structure of measurement and control system

Ta: environment temperature; Ti: Inflow temperature; M: Quantity of flow; To1: Effluent temperature 1; To2: Effluent temperature 2; P: Pressure; Pv: Differential pressure; Fs: Air speed; G, Gd: Solar irradiation;

2.5.2. Software design

The integrated software uses Windows as the operating system, the friendly man-machine way for interaction, the advanced graphical programming language LabVIEW for programming [6], and the multi-user, multi-threaded technology as well as distributed architecture for the task processing. The system software includes modules such as the state machine with LabVIEW as its main body structure, the signal acquisition module of limit signals and servo motor encoder, the movement module of horizontal mobile platform and two-axis solar tracking frame, the real-time tracking test module and data processing module, etc. Figure 5 shows the software structure based on the standard state machine.

During the signal acquisition, all signals emitting from various sensors and servo motor encoders can be mainly acquainted by motion control cards and data acquisition cards. In the motion control module, servo motor movement parameters are set up, such as servo motor pulse mode, encoder feedback, speed direction setting, sport mode settings, and so on. In the data analyzing and processing module, it mainly processes the data analysis, curve fitting, visual display and reports printing. According to user's selection and setting, the integrated software system can automatically control the two-axis tracking frame, test procedure, temperature and flow of the heat transfer fluid. It also can do the self-check and calibration to ensure reliability of the system.

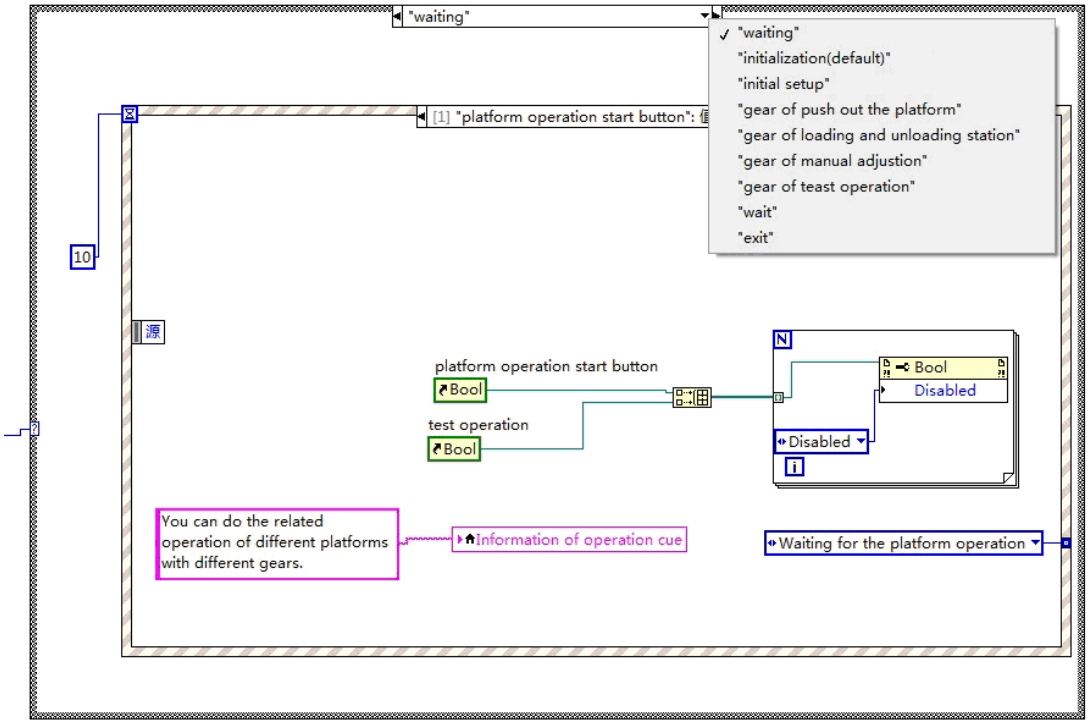

Figure 5. Software structure based on the standard state machine

3. Implementation and testing

According to the design scheme of the previous chapters, a Vehicle-mounted test system was produced successfully, as shown in Figure 6-9. Unlike fixed test system, this vehicle-mounted test system has the following operation principles:

- Non-working status: The back door of the vehicle is closed. Not only the electrical cabinets, water tank, table, computer and printer, but also the automatic tracking frame, the whole test system are placed inside the vehicle.
- Working status: After the test Vehicle arriving at destination, the back door shall be opened first, then the automatic tracking frame automatically be moved out of Vehicle and supported well. Next, the solar collector may be mounted on the tracking frame and be prepared for tests. When the test ends, the tracking frame will be taken back into Vehicle.

Figure 6. Non-working status

Figure 7. Working status

Figure 8. Non-working status

Figure 9. Working status

In order to prove the feasibility and advancement of the vehicle-mounted test system, a number of tests have been done, such as repetition test, calibration, contrastive test, electro-magnetic compatibility test, safety test for vehicle operating on road and so on. These tests have shown that the design scheme is feasible and the vehicle-mounted test system has the following properties:

- It can be applied on thermal performance testing of solar collectors according to the standards of ISO 9806:2013 and GB/T 6424-2007, including outdoor steady-state efficiency test, time constant, incident angle modifier and pressure drop measurement.
- It has high automation: the mounting frame can automatically move out form the vehicle or take back, and track the sun; it can automatically control test procedure and conditions; it can automatically record and analyze data, then print the test report.
- Parameters and performance of the vehicle-mounted test system has many advantages in many aspects compared with Standard requirements, as shown in table 2.

Table 2. Overall comparisons

Parameter/ characteristic		deviation /mode	
		Permitted deviation (ISO 9806:2013)	The Vehicle-mounted Test System
Test solar irradiance		± 50 W/m^2	± 50 W/m^2
Fluid temperature Measurement		±0.1K(inlet), ±0.5K(outlet)	±0.1K(inlet), ±0.1K(outlet)
Fluid inlet temperature control	control accuracy	stable within ±1K	stable within ±0.2K
	Control mode	Two stages	Two stages
Fluid flow rate	Measurement	±1%	±1%
	control accuracy	stable within ±2% of the set value	stable within ±1% of the set value
	response time	/	about 1min
	Stable time	/	maintain more than 15 min
	Control mode	Using a simple bypass loop and manually controlled needle valve	automatic control by Frequency Converter

Data logger	a 12-bit digital system	a 16-bit digital system
Track the sun	manually or Single-dimension tracking	two-dimensional automatic tracking control accuracy :0.2 mm

4. Conclusions

As a movable device, the vehicle-mounted test system can provide door-to-door testing services, which can increase efficiency and shorten test cycle, also has other advantages such as high automation, friendly man-machine interface, simple operation, good mobility and stability. It can be widely used in testing laboratories and manufacturers for thermal performance test of solar collectors to meet the rising demand, and that will obtain great economic and social benefits.

The design of effective integration between vehicle and test device, especially part of devices can be removed out from vehicle and taken back safety and reliably, provides a good reference for the mobile test equipment.

Future research work should be oriented toward increasing the range of temperature control to satisfy the demands of medium-temperature collector test.

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