Stability Test on Power Supply to the Xenon Lamp of Solar Simulator

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Abstract. In this paper, the stability of the electrical control system structure of the typical solar simulator system is studied. Volt-ampere characteristic tests, light-on tests and system-level irradiance stability tests after light-on of xenon lamps with three power supplies were carried out using the solar simulator (KFTA). The solar simulator test is carried out on the current three mainstream input power supplies respectively. The stability test target of the electrical control structure of the solar simulator system is completed, and the irradiation instability is realized which is better than ±1%.

1. Introduction
In order to satisfy the thermal vacuum test of spacecraft, satellites parts test calibration, environmental adaptability test of optical remote sensor, in the field of solar photovoltaic power generation and material properties test requirements, can provide similar to the real distribution of the solar spectrum, uniform and stable and controllable irradiation system is more and more become the key object of study in the field of space science research [1-5].

This kind of irradiation simulation system mainly consists of light source system, uniform light system, imaging system and electrical control system [3, 5]. The rationality of the optical system design directly determines the physical and geometric characteristics of the irradiation surface, such as irradiance, uniformity, stability, spectral distribution, irradiation surface size and quasi right Angle. The electrical control system is the control core of the irradiation simulation system and provides effective power input for the light source system. Its control performance and stability directly determine the uniformity and stability of the irradiation simulation system. Therefore, it is necessary to study the stability test and optimization improvement of the electrical control system [7, 8]. The performance of the electrical control system is generally considered in the following aspects: the stability of the voltage current characteristic curve of the electric energy input of the electrical control system and the stability of the irradiance of the light irradiation surface [7, 8].

In this study, the stability of the voltage current characteristic curve of the electric energy input of the electrical control structure and the stability of the irradiance of the light irradiation surface of three power supplies have been studied.

2. Experiment
The stability test was performed in a solar simulator. The structure of the electrical control system includes working power supply, temperature control power supply, computer, digital-acquisition instrument and cables. The involved optical-mechanical systems include components and equipment
outside the container, such as optical integrator components, baffle components, light screen components, lamp chamber and light source components [6], (Fig.1).

Xenon lamp chose the XBO 10000 W/HS OFR (OSRAM, Germany), with a maximum power of 10000W and air cooling. The SGI80/250D-1CAA power supply (ELGAR, USA) (working voltage:50V and working current: 200A) was applied in the anti-interference performance improvement test based on irradiance measurement of the solar simulator system. The light-on tests of Xenon lamps with three power supplies by the reconstructed SGI 60/250D-1CAA (AMETEK, USA), Agilent8952A (USA) and EA-PSI 9200-210 (EA, Germany) were carried out. The trigger model was input voltage ≥150VDC and triggering voltage ≥30kV. Temperature in the optical-mechanical system was measured by HEWLETT 34970A digital acquisition-switch unit temperature measuring instrument. To increase measurement accuracy and analyze the interference signal, another two measuring instruments were equipped in the test: Agilent 6705+6701 and oscilloscope MSO-X 3054A(500MHz). The 34970 is characteristic of low sampling rate, but high accuracy, and it can communicate computers through the GPIB interface. The 6705+6701 shows high sampling rate and moderate accuracy, and it can realize data local-storage. The oscilloscope has high sampling rate, but low accuracy, and it can analyze interference signal intensity. The irradiance of silicon photocell was tested by the built-in software of Agilent and the measured value of irradiance was recorded.

![Fig.1 Structure of the irradiance measuring system of xenon lamp](image)

### 3. Test and result analysis

#### 3.1 Anti-interference performance improvement test

KFTA is interfered significantly when measuring the irradiance signal of xenon lamp. After analysis of possible causes of interferences, KFTA was improved by following methods:

- **Method 1**: The system irradiance was measured after the use of shield cables
  
  The irradiance acquisition signals of xenon lamp have two sections of cables from the silicon photocell to the computer. The silicon photocell was connected with digital-acquisition instrument by ordinary cables. Now, this cable was replaced with shield cables and the length shall be decreased as much as possible in order to decrease interference of external signals.

- **Method 2**: A filter was added in the input end of digital-acquisition instrument.
  
  The input end of digital-acquisition instrument is added with a low-pass filter for filtering and anti-interference and inhibiting interferences of harass harmonic waves from electrical equipment in the system to data acquisition effectively.

- **Method 3**: Interferences to the temperature controlling instrument were observed.

The irradiance of silicon photocell was tested by the built-in software of Agilent and the measured value of irradiance was recorded.
Interferences of switching temperature controlling instrument to acquisition of feedback voltage signals of silicon photocell based on KFTA were observed. After the temperature controlling instrument was turned on, since a strong electromagnetic interference was generated by the internal power supply module to influence acquisition of voltage signals, the interference intensity was judged by tests.

In the test, feedback voltage signals of silicon photocell were collected firstly on the non-reconstructed KFTA. The peak-to-peak value of feedback voltage was tested 43 mV before turning on the temperature controlling instrument, but it increased to 127 mV after the temperature controlling instrument was turned on. This reflects that the temperature controlling instrument causes great interferences to measuring signals, which is related with the structure of internal power supply module. A strong electromagnetic interference will be produced after the temperature controlling instrument is turned on. Later, the KFTA equipment were reconstructed. In the beginning, a filter was added in the power input end of digital-acquisition instrument. After filtering, the peak-to-peak value of feedback voltage of silicon photocell was measured 37 mV before turning on the temperature controlling instrument, but it increased to 106 mV after the temperature controlling instrument was turned on. This reveals that the filter is useful to some extent and it decreases the interferences by 16.5%. Subsequently, the cable between the silicon photocell and digital-acquisition instrument was replaced by shield cable based on the connection of an additional filter. The peak-to-peak value of feedback voltage of silicon photocell was measured 27 mV before the temperature controlling instrument was turned on, but it increased to 79 mV after. The interferences decreased by 37.8% after the overall reconstruction (Table 1).

Table 1 Working conditions for the anti-interference performance improvement test

| No. | Filter added? | Temperature controlling instrument turned on? | Shield cable used? | Peak-to-peak value (mv) | Improvement in comparison to Working condition 1 (%) | Improvement in comparison to Working condition 2 (%) |
|-----|---------------|-----------------------------------------------|-------------------|-------------------------|---------------------------------|---------------------------------|
| 1   | No            | No                                            | No                | 43                      | ————                           | ————                           |
| 2   | No            | Yes                                           | No                | 127                     | ————                           | ————                           |
| 3   | Yes           | No                                            | No                | 37                      | 13.9                            | ————                           |
| 4   | Yes           | Yes                                           | No                | 106                     | ————                           | 16.5                           |
| 5   | Yes           | No                                            | Yes               | 27                      | 37.2                            | ————                           |
| 6   | Yes           | Yes                                           | Yes               | 79                      | ————                           | 37.8                           |

3.2 Volt-ampere characteristics of testing circuit of xenon lamp

The dual-power light-on circuit principle of single xenon lamp is shown in Fig.2(a). During the light-on process of xenon lamp, three voltages are needed, namely, trigger voltage, open-circuit voltage and working voltage. Specifically, the trigger voltage, or known as instantaneous voltage, is to breakdown inert gases between the anode and cathode of xenon lamp, and it is off immediately after the light-on of the xenon lamp. The open-circuit voltage is the open-circuit voltage between the anode and cathode of xenon lamp before the light-on and it is to expand the spark channel, further heat the cathode, accelerate start-up of the xenon lamp and enter into the arc discharge. The working voltage is the voltage under normal working state after the xenon lamp is lighted on.

![Fig.2 Dual-power light-on circuit of single xenon lamp and simplification](image-url)
In the working process, the two-phase switches S2 and S3 of auxiliary power supply were closed firstly to supply an open-circuit voltage to the xenon lamp and accelerate the start-up and entrance of the xenon lamp into the arc discharge process. Later, the contact switch S1 was triggered by point and 220V AC ran through the trigger. The trigger generated a high instantaneous voltage to breakdown the insert gases between the anode and cathode of the xenon lamp, thus turning on the xenon lamp. At this moment, S2 and S3 were off, and the auxiliary power supply was stopped. Instead, the working voltage began to supply power to the xenon lamp. The circuit used the capacitance C1 as insulation protection of the system. Based on DC separation and AC running of C1, a light-on circuit is provided to the xenon lamp after the trigger is started on, which assures the smooth light-on of the xenon lamp.

In the test, volt-ampere characteristics of the major loop of the working power supply (AMETEK SGI80/250D-1CAA), the loop of working voltage and the loop of auxiliary power supply to the KFTA were tested firstly by using the dual-channel oscilloscope MSO-X 3054A (Agilent). One channel is equipped with a current clamp that supports 200A to measure current and the other channel is used to measure voltage. The volt-ampere characteristic curve of the xenon lamp was acquired by recording the voltage and current values.

Volt-ampere characteristics of the major loop: The initial current was 0A and the current was climbed to 155A at about 130 μs after clicking the trigger button. Subsequently, the growth slope of current began to decline. The initial voltage was 173V and the voltage dropped to 74V at about 200 μs after clicking the trigger button. Finally, the voltage was stabilized at 35V. The waveforms are shown in Fig.3.

Volt-ampere characteristics of loop of the working voltage: the initial current was 0A and it began to increase from the clicking of the trigger button to about 260μs. It was further climbed to 215A in another 250μs and then the growth slope of current began to drop. The current reached the peak (590A) after clicking the trigger button for about 1.3ms. The initial voltage was 80V and it dropped to 36~40V at about 6.2ms after clicking the trigger button. The waveforms are shown in Fig.4.
Volt-ampere characteristics of the loop of auxiliary power supply: the initial current was 0A and the current began to increase since the clicking of the trigger button. The current reached the peak (175A) at 160μs, and then dropped to 7.2A after 140μs. Subsequently, the current is basically kept stable between 11A~17A. 1ms later, the current increased to about 63A again. The light-on voltage waveforms of the xenon lamp is shown in Fig.3-a, which shows the volt-ampere characteristics of the loop of AMETEK SGI 80/250D-1CAA auxiliary power supply. The initial voltage was 173V and the voltage dropped to 72V at about 200μs after the clicking of the trigger button. Finally, the voltage was stabilized at 46V. Waveforms are shown in Fig.5.

Fig.5 Loop of auxiliary power supply in the volt-ampere characteristic test of the xenon lamp circuit

3.3 Volt-ampere characteristic curve of testing power supplies
Since rated voltages of all three power supplies are higher than the open-circuit voltage (150V) of the xenon lamp, the circuit in Fig.2 can be simplified. The auxiliary power supply is eliminated and the power supply for the KFTA is reconstructed to the circuit in Fig.6 to test the volt-ampere characteristic curve of the xenon lamp. The simplification of circuit is of important significance to KFTA. It is not necessary to set a diode in the circuit if there’s no auxiliary power supply. Since the previous design has a diode in the loop of working voltage to avoid backflow of working voltage and the diode is in the working environment all the time, it consumes energies and generates tremendous heats. It is necessary to be equipped with a special fan for the diode, which occupies a certain volume of the control cabinet. Besides, KFTA uses 37 high-power xenon lamps in the same time and stability of power supply is vital. Therefore, the testing power supplies have to be tested thoroughly. The testing results of volt-ampere characteristics of three power supplies are shown in Table 2.
When 37 xenon lamps of KFTA are turned on simultaneously, the triggering performance of power supplies have important significance to normal light-on of xenon lamps. According to above analysis of volt-ampere characteristics of power supplies, the time to maintain the lowest current can influence normal light-on of xenon lamps to some extent. The duration of the minimum current is the shorter, the better, and the minimum current is the higher, the better. This indicates that electric arc has great energies and it is difficult to be quenched, which is beneficial start-up of the xenon lamps. Besides, a small slope is conducive to turn on the lamp during the reduction stage of current after the peak and current has a certain buffer stage. According to a comprehensive comparison, all three power supplies can meet the triggering requirements to turn on the xenon lamps and AMETEK is superior the rest two power supplies in term of triggering performance of the xenon lamps.

3.4 System irradiance stability after light-on of testing xenon lamps

The system irradiance stabilities after the light-on of testing xenon lamps with three power supplies were tested one by one according to the system in Fig.1. Temperature in the optical-mechanical system was measured by the HEWLETT 34970A digital acquisition-switch unit temperature measuring instrument. The irradiance sensor used the silicon photocell which is equipped with silicon photocell sheets and has a nonlinear error no higher than 0.5%. The silicon photocell is the core component in the irradiance measuring system and the detector size is generally 20mm×20mm. The irradiance measuring range with good linear output was between 0-2 solar constant. It was connected to a small resistor in parallel and the resistance was no higher than 1Ω. The voltage of the resistor was measured and the output value at 1 solar constant was about 16mV. The output signal changes with variation of temperature. Temperature of the silicon photocell shall be controlled during irradiance measurement and the silicon photocell shall be calibrated under the temperature in the service environment. The chosen silicon photocell detector was an encapsulation product. The irradiance output and temperature output were connected to cables through a 7-pin interface.

The output power was set 7kW and the measured irradiance values in 15~20 minutes were recorded after being stabilized for 30 minutes. After finishing the tests, irradiance stabilities of three power supplies were compared. The system irradiance stability testing results after light-on of the xenon lamps are shown in Table 3.

| Power supply         | Steady voltage (V) | Steady current (A) | Irradiance stability (%) |
|----------------------|--------------------|--------------------|----------------------------|
| Agilent N8952A       | 45.5               | 155                | 0.73                       |
| EA-PSI 9200-210      | 45.3               | 155                | 0.69                       |
| AMETEK SGI 60/250D-1CAA | 45.7            | 155                | 0.74                       |

The irradiance voltages of three power supplies were measured after stabilization of xenon lamps for 0.5h, which were 0.73%, 0.69% and 0.74%. Waveforms are shown in Fig.7. The testing results of
irradiance stability under three power supplies were relatively similar and all conformed to the index that the irradiance stability no higher than ±1%.

Fig.7 Waveforms of system irradiance stability of the three power supplies

4. Conclusions
The anti-interference performance of KFTA in system irradiance measurement is improved in this study. Three power supplies, including SGI 60/250D-1CAA (AMETEK, USA), Agilent8952A (USA) and EA-PSI 9200-210 (EA, Germany), are used to test the volt-ampere characteristic curve of xenon lamps. Whether xenon lamps can be lighted on normally without auxiliary power supply is assessed. The system irradiance stability is tested by using existing systems of KFTA after the light-on of xenon lamps. Results show that all three power supplies can meet the triggering requirements to light on xenon lamps. Moreover, AMETEK is superior to the rest two power supplies in term of triggering performances of xenon lamps. The test results of irradiance stability of three power supplies are similar and all conform to the index that irradiance stability no higher than ±1%. The testing schemes and testing results can provide references to the design and manufacturing of solar simulator.

References
[1] Tawfik, M., Xavier Tonnellier, and C. Sansom. "Light source selection for a solar simulator for thermal applications: A review." Renewable and Sustainable Energy Reviews 90 (2018): 802-813.
[2] Enaganti, Prasanth K., et al. "Analysis of submerged amorphous, mono-and poly-crystalline silicon solar cells using halogen lamp and comparison with xenon solar simulator." Solar Energy 211 (2020): 744-752.
[3] Wang, Wujun, et al. "Development of a Fresnel lens based high-flux solar simulator." Solar Energy 144 (2017): 436-444.
[4] Codd, Daniel S., et al. "A low cost high flux solar simulator." Solar Energy 84.12 (2010): 2202-2212.
[5] Petrasch, Joerg, et al. "A novel 50kW 11,000 suns high-flux solar simulator based on an array of xenon arc lamps." (2007): 405-411.
[6] Leary, Gregory, et al. "Comparison of xenon lamp-based and led-based solar simulators." 2016 IEEE 43rd Photovoltaic Specialists Conference (PVSC). IEEE, 2016.
[7] Dominguez, César, Ignacio Antón, and Gabriel Sala. "Solar simulator for concentrator photovoltaic systems." Optics express 16.19 (2008): 14894-14901.
[8] Gill, Robert, et al. "Characterization of a 6 kW high-flux solar simulator with an array of xenon arc lamps capable of concentrations of nearly 5000 suns." Review of Scientific Instruments 86.12 (2015): 125107.