URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Short-circuit current processing method in space calibration of "twin" solar cells

Sun Huicong(1),Liu Min(1), Zhang Yu (1), and Mei Gaofeng(1)
(1)Beijing Orient Institute of Measurement & Test
Beijing 100086, China
Phone: 19801317081, Email：903490201@qq.com

Abstract

In order to obtain the short-circuit current of solar cells under the condition of AM0 (Air Mass Zero), so as to achieve the spatial calibration of standard solar cells, this study uses the "twin" solar cell spatial calibration method. First, a batch of paired batteries that meet the requirements is selected. One of the paired batteries enters the space with the satellite, and the short-circuit current and temperature are measured under AM0 conditions, and the other is left on the ground. This article discusses the correction method of short-circuit current data transmitted back from the satellite, including the acquisition error correction of the data acquisition instrument, temperature correction, AM0 light intensity correction, twin inherent error correction, and space ray particle influence correction. The data of the solar cells on the satellite are assigned to the ground solar cells after correction, and AM0 standard solar cells are obtained on the ground.

1 Introduction

With the development and application of various new space solar cells such as multi-junction gallium arsenide solar cells, On the ground, the method of using the solar simulator to calibrate AM0 (Air Mass Zero) standard solar cells has encountered serious difficulties both in theory and in practice[1]. The space calibration that reflects the actual use of solar cells has become an ideal solution to the problem.

In order to achieve standard solar cell space calibration, the solution is obtaining short-circuit current data for solar cells under AM0 conditions. Thus, Beijing Orient Institute of Measurement and Test uses the "twin" solar cell space calibration method to perform space calibration on one AM0 silicon solar cell and 26 single-junction solar cells of the multi-junction standard solar cells. The solar cell was successfully calibrated in January 2020, and the corresponding calibration data was obtained. The first set of data includes short-circuit current, temperature, measurement time, and orbit data (including attitude angle) of 13 sub-cells and 1 AM0 silicon battery, the second set of data includes volt-ampere characteristic data, temperature, measurement time, orbit data (including attitude angle) of 13 sub-cells.

Solar cell calibration refers to testing the short-circuit current of solar cells under standard conditions (STC, Standard Test Condition) at AM0 spectral distribution, light irradiance of 1367W/m^2, and 25±1°C[2].

The solar cell short-circuit current data sent back to the ground from the satellite still needs a series of error corrections before the value can be assigned to the solar cell on the ground, so that AM0 standard solar cells can be obtained on the ground. This article will analyze the error correction factors to be considered according to the calibration process of solar cells on satellites, and give the correction methods.

The “twin” solar cell space calibration method used in this space calibration must firstly select a pair of matched batteries that meet the requirements on the ground. This article uses a pair of "twin" solar cells A1 and A2 as an example: one of the paired solar cells A2 stays on the ground, and the other solar cell A1 goes one-way into space with the satellite, the data of the solar cell A1 is collected by a data acquisition instrument, and then the solar cell A2 on the ground is assigned to obtain the AM0 standard solar cell.

The following analyzes correction factors that need to be considered in the assignment process.

(1) When the data acquisition instrument collects the short-circuit current data and temperature data of the solar cell, it has its own acquisition error. So it is necessary to consider the data acquisition instrument's acquisition error of the 14 cells short-circuit current data and temperature data.

(2) In space, the solar spectrum shining on a solar cell is the AM0 spectrum, but because the distance between the satellite and the sun is not exactly 1AU, the illumination intensity of the solar cell on the satellite is different from the illumination intensity under standard conditions, so the measured short-circuit current data needs to be corrected to the light intensity of 1367W/m^2.

(3) The temperature of the solar cell on the satellite cannot be guaranteed at 25±1°C. So the short-circuit current data of solar cell A1 needs to be corrected to the short-circuit current data at a temperature of 25°C.

(4) Due to the differences between the "twin" solar cells, the inherent differences between the "twin" cells A1 and A2 must also be considered. In the process of assigning the short-circuit current value of A1 to A2, the inherent error between the "twin" solar cells must be considered.

(5) A1 in the "twin" solar cell is placed in a space environment, and will be affected by particles and rays in space. It is necessary to consider the impact of these factors on the consistency between twins.

The following will discuss how to modify these influencing factors, and illustrate the process of correction.

2 Acquisition error correction of data acquisition instrument

When the data acquisition instrument collects the short-circuit current data and temperature data of the solar cell, it has an acquisition error. This section illustrates the calibration details of short-circuit current data and temperature data, calibration methods, and calibration principles for 13 sub-cells and 1 AM0 silicon cell.

2.1 Calibration of short-circuit current data

Before loading, use the data acquisition instrument to collect the standard current value, and compare the acquired value with the standard current value. It is found that the data acquisition instrument 's collection error of the current data is a linear deviation, Therefore, when the original short-circuit current data uploaded by the satellite is modified here, the original short-circuit current value is multiplied by the corresponding slope and the intercept is added to obtain the corrected short-circuit current value.
A standard source is used to sequentially decrease the current value of 170mA ~ 50mA. The data collector collects the standard current value, collects the same named value for 20 times, and records the average value of the 20 collected values. Draw the curve with the standard value as the abscissa and the acquisition value as the ordinate. Use the slope and intercept to modify the drawn curve to a curve with an intercept of 0 and a slope of 1. The selected intercept and slope are differ from another for the 14 sub-cells with their shunt resistor on the satellite.

2.2 Calibration of temperature data

The circuit diagram of the temperature acquisition circuit of the data acquisition instrument is shown in Figure 1. It consists of a thermistor and a voltage divider network.

$$T_x = \frac{2c}{-b+\sqrt{b^2-4c(a-\ln R_t)}} - 273.15 \qquad (1)$$

The a=-2.12352, b=3688.933, c=-108944.9.

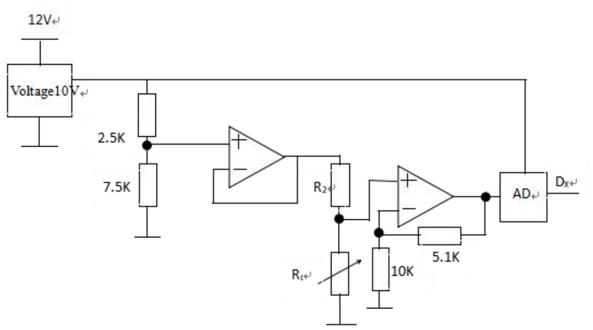

Figure 1 Temperature acquisition circuit of the data acquisition instrument

The relationship between the measured average value D_x and the thermistor R_t obtained through the voltage dividing network of the circuit is as follows:

$$D_x = \frac{R_t}{R_t+R_2}\times 7.5\times\frac{10k+5.1k}{10k}\times\frac{65536}{10} = \frac{R_t}{R_t+R_2}\times 74219.52 \qquad (2)$$

The R_2 is divided resistor, the resulting R_t expression is as follows:

$$R_t = \frac{D_x}{74219.52-D_x}\times R_2 \qquad (3)$$

For temperature calibration, the temperature value can be obtained by substituting the value of the divided resistor in each channel and the measured average value D_x returned by the satellite into the following formula.

$$T = \frac{2\times(-108944.9)}{-3688.933+\sqrt{3688.933^2-4\times(-108944.9)\times\left(-2.12352-LN\left(\frac{R_2}{\frac{74219.52}{D_x}-1}\right)\right)}} - 273.15 \qquad (4)$$

Use a data acquisition instrument to collect the standard resistance value of the standard resistance R_1 at different temperatures, and compare it with the standard resistance value. The actual deviation is converted to the voltage divider resistance. The resistance value of the voltage divider resistance is calculated by the following formula. 7.5V.

$$R_2 = R_1\times\left(\frac{74219.52}{D_x}-1\right) \qquad (5)$$

Different standard resistors are selected at different temperatures, which corresponds to different divided resistors. The temperature calibration of the short-circuit current of the 14 sub-cells uses their respective divided resistors.

2.3 An acquisition error correction example of data acquisition instrument

When correcting the short-circuit current acquisition error of the data acquisition instrument, the slopes and intercepts of the sub-cells 1 to 3 used are shown in table 1.
To correct the temperature acquisition error of the data acquisition instrument, according to the temperature data of the solar cell on the satellite, select a standard resistance of 1.885kΩ on the calibration certificate corresponding to the divided resistors at 76°C. Each of the 14 sub-cells uses its own divided resistor. Substituting the divided resistor value and the measured source code into equation (4) to get the corrected temperature value.
Taking sub-cells 1 to 3 as an example, the results of the original short-circuit current data corrected by the data acquisition instrument are shown in table 1. The

measurement uncertainty of the data collector current is less than 0.1%, and the measurement uncertainty of the temperature is less than 0.2°C.

Table 1 Acquisition error correction results of the data acquisition instrument for the short-circuit current of the sub-battery

number of the battery	Raw short-circuit current data /mA	Data collector calibration results			
		Temperature /°C	Short-circuit current /mA	Slope	intercept
1	69.56	76.9	69.58	1.00039	-0.0045
2	69.23	77.0	69.26	1.00054	-0.00705
3	113.26	76.4	113.27	1.00004	-0.0012

3 Correct the short-circuit current of solar cells according to temperature

The calibration of aerospace standard solar cells requires a temperature of 25±1°C.When the solar cell enters space, the temperature cannot be guaranteed at 25±1°C, so the measured short-circuit current data of the solar cell must be corrected.

3.1 The principle of correcting the short-circuit current of solar cells according to temperature

Before the solar cell is installed, test the short-circuit current temperature coefficient of the solar cell. First connect the temperature control and temperature measurement device of the solar cell, set the temperature at 25±1°C, and then adjust the irradiance of the solar simulator to 1367W/m^2 to measure the short-circuit current of the solar cell. Let the temperature of the solar cell continue to increase, and measure the short-circuit current of the solar cell in sequence after the temperature stabilizes, until it reaches the highest point of the required temperature range. Then use statistical methods to process the data and draw the temperature curve of the short-circuit current. Find the slope of the curve at the midpoint of the required temperature range, which is the temperature coefficient α of the short-circuit current.[3]

$$I_{sc2} = I_{sc1} + \alpha(T_2 - T_1) \tag{6}$$

T_1 is the temperature of the sub-cell collected by the data acquisition instrument on the satellite; T_2 is the standard temperature of 25°C, I_{sc1} is the short-circuit current before calibration, and I_{sc2} is the short-circuit current after calibration. The Temperature coefficient measurement uncertainty is 0.01mA/°C

3.2 Example of temperature correction

Here take the sub-cells 1 to 3 as an example. Given the temperature coefficient of the sub-cell and the temperature of the sub-cell on the satellite, the short-circuit current data of the sub-cell on the satellite can be corrected to 25°C according to formula (6) .

Temperature correction is performed on the basis of the data corrected by the data collector in Section 2.3. The results after temperature correction are given in Table 3.

4 Irradiance correction

On satellites, the spectrum of sunlight shining on solar cells is the AM0 spectrum, but the light intensity is different from the light intensity under standard conditions. The measured short-circuit current data of the sub-cell needs to be corrected to an intensity of 1367 W / m^2 (1AU) light.

4.1 Principle of Irradiance Correction

The irradiance should be corrected to the standard irradiance of 1AU, and the effect of irradiance on the short-circuit current is expressed by formula (7)[4].

$$I_{SC_{Sun}} = \frac{I_{SC}}{\cos(\theta)}\left(\frac{1AU}{xAU}\right)^2 \tag{7}$$

In this formula, x is the distance between the sun and the earth in AU, I_{sc} is the data before the correction, Isc_{sun} is the data after the correction, and θ is the angle. During the satellite's orbital change, the attitude of the satellite was constantly adjusted so that the face aimed at the sun, and the incident angle of the sunlight to the solar cell was θ=90±1°.

4.2 Example of irradiance correction

In the J2000 coordinate system, the coordinate information of the satellite and the sun at the corresponding short-circuit current collection time is as follows:

The satellite coordinates are as follows:

X_1 = -39734318.0, Y_1 = -21859385.1, Z_1 = -35200.0. (Unit m)

The coordinates of the sun are:

X_2 = -27859507709.0, Y_2 = 132516960894.6, Z_2 = -57446475173.0. (Unit m)

Distance between satellite and sun：

r = 147107349028.09 (m) = 0.9835AU

Substituting the value of r into equation (4-1) gives:

$$I_{SC_{sun}} = 0.9835 I_{sc} \tag{8}$$

The correction results of the short-circuit current irradiance based on the temperature correction results of the short-circuit current of the battery in Section 3.2 are given in Table 3.

5 Intrinsic error correction of "twin" solar cells

There are still slight differences between the matched "twin" solar cells A1 and A2. In order to accurately assign the short-circuit current value of solar cell A1 to A2, the inherent differences between the twins still need to be corrected.

5. 1 Correction method for inherent errors between twins

Before mounting, test the short-circuit current of the paired solar cell at 25°C. Record the difference in the short-circuit current between sub-cell A1 and sub-cell A2 according to Equation (9). After the short-circuit current of the satellite solar cell A1 is obtained, the short-circuit current of the ground solar cell A2 can be calculated.

$$a = \frac{(I_{SC_{A1}} - I_{SC_{A2}})}{I_{SC_{A1}}} \times 100\% \qquad (9)$$

5.2 Examples of correction of twin inherent errors

The difference between the short-circuit current data of the sub-cells 1 to 3 carried on the satellite and the short-circuit current data of the sub-cell paired with the ground is calculated as shown in Table 2 according to formula (8).The results of the twin error correction are shown in Table 2.

Table 2 Differences in short-circuit current data of sub-cells 1 to 3

Serial number of the sub-battery	Short-circuit current data difference（a）
1	-0.137%
2	-0.024%
3	-0.301%

Based on Section 4.2, the inherent twin error correction of the short-circuit current is performed. The results are shown in Table 3.

Table 3 "Twins" inherent error correction results

number of the battery	Raw short-circuit current data /mA	Data collector calibration results		Temperature correction		Irradiance correction /mA	Twin inherent error correction /mA
		temperature /°C	Short-circuit current /mA	Sub-battery temperature coefficient /(mA/°C)	Short-circuit current /mA		
1	69.56	76.9	69.58	0.039	71.58	70.40	70.50
2	69.23	77.0	69.26	0.21	80.12	78.80	78.82
3	113.26	76.4	113.27	-0.05	110.95	109.12	109.45

6 Impact of space environment on the performance consistency of "twin" solar cells

The existence of a large number of rays and high-energy particles in the space environment will affect the performance of the solar cells carried on the satellites, and then affect the consistency of the twin solar cells[5].

In order to estimate the impact of space rays and particles on solar cells, data acquisition experiments were performed in the shortest time of the satellite (after the fifth orbit of the satellite). The short-circuit current data of the sub-cells at the spring equinox point, autumn equinox point, and the 22nd of each month in 2020 were collected and compared with the short-circuit current data measured after the fifth orbital change for further comparison. Analyze the impact of the space environment on the solar cell, and correct the impact of the space environment on the short-circuit current of the solar cell.

7 Conclusion

This article describes the calibration of short-circuit current data for 14 sub-cells, including calibration principles and calibration methods. Taking sub-cells 1 to 3 as examples, the data acquisition instrument correction, temperature correction, irradiance correction, and inherent error correction between the "twin" solar cells were respectively performed on the short-circuit current data. After getting enough data, we will further analyze the impact of space environment on the consistency of "twin" solar cells. And establish a modified mathematical model to estimate the short-circuit current calibration value of solar cell A2 by using the short-circuit current data uploaded by satellite A1 in the "twin" solar cell on the satellite. The uncertainty of the short-circuit current data of solar cells obtained on the ground does not exceed 1%. Finally, a space-level AM0 standard solar cell is obtained on the ground.

The obtained space-level AM0 standard solar cell will provide technical guarantee for the establishment of accurate and reliable ground calibration equipment for new aerospace standard solar cells, and provide experimental verification for the establishment of China's space solar cell calibration system.

8 References

1. Zhang Ya, Yuan Yafei, & Tang Haojun. Preliminary Exploration of Solar Cell Space Calibration Technology [J]. *Aerospace Measurement Technology* 2010, (01), 32-36.

2. IEC60904:200x Photovoltaic devices - Part 4: Reference solar devices - Procedures for establishing calibration traceability[S].

3. IEC 60904-9:2008 Edition 2.0 Part 9: Solar Simulator Performance Requirements[S],.

4. Jenkins, P. P. , Walters, R. J. , Greer, L. C. , Krasowski, M. J. , & Boca, A. . (2008). In-flight performance of III-V multi-junction solar cells from the Forward Technology Solar Cell Experiment [C]. Photovoltaic Specialists Conference, 2008. PVSC '08. 33rd IEEE. IEEE.

5. Li Tao, Jiang Lixiang, Guo Liang, Liu Xiangpeng, Feng Weiquan, & Zhai Ruiqiong. (2010). Analysis of the impact of space atomic oxygen environment on solar cell arrays[J]. *Spacecraft Environmental Engineering*, 2010, 27 (4), 428-433.