International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:4, No:9, 2010

Infrared Lamp Array Simulation Technology Used during Satellite Thermal Testing

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***Abstract*—**A satellite is being integrated and tested by BISEE (Beijing Institute of Spacecraft Environment Engineering). This paper describes the infrared lamp array simulation technology used for satellite thermal balance and thermal vacuum test. These tests were performed in KM6 space environmental simulator in Beijing, China. New software and hardware developed by BISEE, along with enhanced heat flux uniformity, provided for well accomplished thermal balance and thermal vacuum tests. The flux uniformity of lamp array was satisfied with test requirement. Monitored background radiometer offered reliable heat flux measurements with remarkable repeatability. Simulation software supplied accurate thermal flux distribution predictions.

***Keywords*—**Satellite, Thermal test, Infrared lamp array, Heat flux

I. Introduction

A satellite is currently being integrated and tested by BISEE for launch in 2010. BISEE designed and executed the spacecraft level thermal testing in the KM6 thermal vacuum chamber which is the biggest one in Asia. Both thermal balance and thermal vacuum tests used an infrared simulation test technique.

New technology improvements and system enhancements were developed for satellite thermal test. A software module named ADSTT was created to predict lamp location needed to achieve specified flux uniformity targets for each zone. Monitored background radiometer were mounted near the spacecraft to measure actual thermal flux input during the test and allowed for real-time flux adjustments. During the tests, advanced facility test systems were used to control heat input levels and monitor thermal activity.

II. BISEE Infrared Lamp Array Technology Overview

Infrared lamp array has been used for 2 decades at the BISEE and is generally more advantageous than other flux simulation methods. The objective of this test technique is to generate accurately known heat flux inputs to defined zones on the spacecraft. The thermal engineer uses this data to modify thermal mathematical model at the thermal balance testing. The same heat sources can also be used as the major inputs to drive the various parts of the spacecraft to required temperatures during the remainder of the thermal vacuum testing [1].

This is a cost effective technique for performing accurate thermal balance and thermal vacuum testing on spacecraft. There is no need to break vacuum during the entire test which allows for direct transition between thermal balance and thermal vacuum test phases. This test method also permits the testing of small and mid-size satellites in smaller, lower cost thermal vacuum chambers.

Over the past 20 years, many thermal tests have been performed with infrared lamp array at the BISEE on spacecraft which include the following programs: CE lunar satellites, SINO communication satellites, and Shenzhou spacecrafts [2].

III. Infrared Lamp Array Overview

In satellite thermal test, infrared lamps were used. The typical infrared lamp is of a tungsten filament enclosed in a quartz envelope. The lamp resistance at ambient temperature is about 2.3Ω [3]. The resistance could vary over one order of magnitude depending on the filament temperature. Therefore, the spectral region changes with the electrical current (see figure.1).

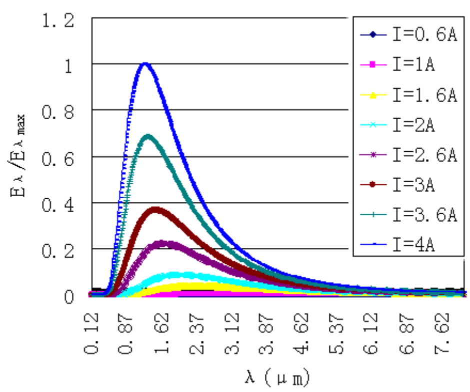

Fig. 1 Spectral output of infrared lamp

The thermal test setup is dependent on the spacecraft configuration, chamber and program requirements. Some dozens of characterized tungsten quartz infrared lamps mounted within highly reflective baffles provided radiant heat

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within the various zones. These baffles increased flux uniformity and intensity onto the spacecraft surface and were arranged around the spacecraft to divide external surfaces into zones to achieve defined heat flux targets and to limit flux leak-out to other zones. Software was used to predict flux uniformity and determine optimal lamp configuration. Sensors were used during testing to measure absorbed thermal flux.

IV. Lamp Array Prediction Software – ADSTT

ADSTT (Analysis and Design Software for Thermal Test) is software used by the thermal test designer in determining the optimal lamp array to obtain the required heat input as dictated by design requirements. It also predicts the thermal flux uniformity for a given zone and lamp levels. Flux prediction is important to ensure uniformity over spacecraft surfaces since the limited number of thermal flux sensors does not allow confirmation of this during testing. It also allows the test designer to ensure there is enough lamp power margin for test flexibility.

Software has visual graphing capabilities (see figure 2). ADSTT uses lamp characteristics, surface properties and zone geometry to calculate the accumulated thermal flux distribution based on Monte Carlo method [4,5]. The reflectivity, absorptivity and transmissivity of quartz envelope are investigated. The heat flux distribution of infrared lamp was tested under low temperature and vacuum environment. Comparing the computed result with the experimental data showed a deviation less than 5% [6]. The analysis method is successfully used to calculate the heat flux distribution of infrared lamp array in a satellite thermal test.

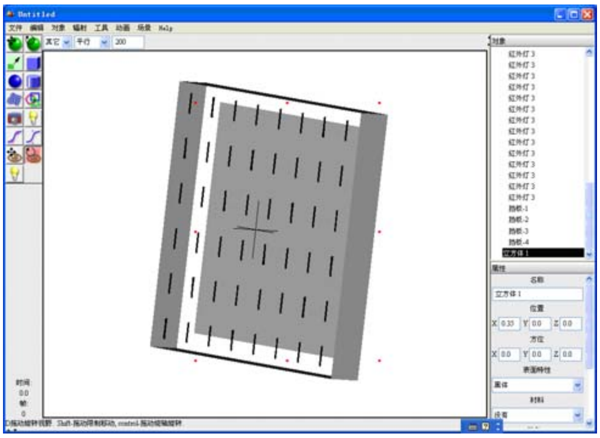

Fig. 2 ADSTT software interface

The software requires the user to input the baffled zone dimensions, baffle surface reflectivity and emissivity along with the target uniformity for the given zone prediction. Lamp height is also required. The software output produces a preliminary lamp arrangement based on these inputs which can be modified by optimization module. Genetic algorithm is used to establish the optimization design method of infrared lamp array. The optimization target is that the uniformity of heat flux distribution could meet the requirement.

V. Thermal Flux Measurement

Monitored background radiometer (MBR) is used to actually measure the heat flux absorbed by the satellite surface. The calorimeter is approximately 3.5 cm in diameter which consists of a sample disc mounted in a cup-like enclosure and thermally isolated from it [2]. The outer surface of the sample disc is covered with the test article material. A temperature sensor mounted inside the sample disc measures the temperature which can be correlated to the value of absorbed flux. The calorimeter is calibrated by applying a known amount of heat to the sample disc.

VI. Satellite Thermal Test Setup

The satellite thermal test equipment setup included a thermal infrared rig installed around the spacecraft after it was mounted on the "L" bracket. Several lamped zones with hundreds individually controlled lamps were used for satellite testing. The baffle zone definitions were determined in consultation with thermal engineers while lamp numbers and their placement were defined by ADSTT software. All baffles and lamps were installed on the "L" bracket and configured for test prior to moving the bracket into the chamber.

The heat flux is simulated by means of heat sink, liquid nitrogen cold plate, infrared cages and infrared lamp array. Heat sink temperature < 100K, and the hemispherical emissivity of heat sink > 0.90. Standard baffles were made of stiff panels with a surface reflectivity of >0.90. The chamber pressure < 1.3×10^{-3} Pa.

The launch vehicle interface adapter was the mounting surface for the spacecraft inside the chamber. The mounting interface was thermally guarded using the automated heat flux control system. Test cables and interfaces were also thermally controlled using this system.

MBRs were located in key areas of interest as determined by thermal engineers. MBR sensors were located close to spacecraft surfaces to ensure measured values correlated well with actual absorbed fluxes on the spacecraft (see figure 3).

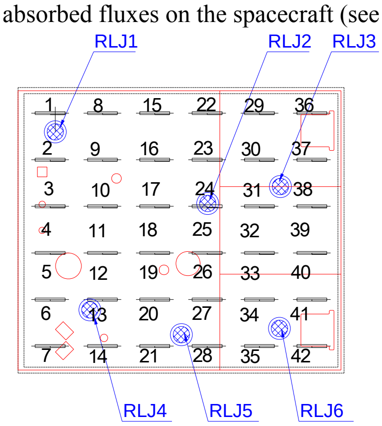

Fig. 3 MBR sensors location

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VII. Test Monitoring and Control System

The heat flux control system (HFCS) is used to control the lamps, IR cages and test heaters power levels during testing (see figure 4). It offers over 300 separate DC power supplies for thermal control of satellite test. Agilent and HP power supplies are used by BISEE. The majority of these channels are used to power individual lamps and recovery heaters during testing. Required lamps levels are achieved by adjusting their current settings. HFCS allows control channels to be grouped which facilitate multiple lamp level changes required to adjust the thermal flux level for a given zone. Moreover, HFCS controls heaters used to regulate heat flow out of the test article. In automatic mode, the controller can apply heater power as required to have the control thermocouple match the temperature of the target thermocouple. Other features include manual control, current restrict, alarms and PID adjustments.

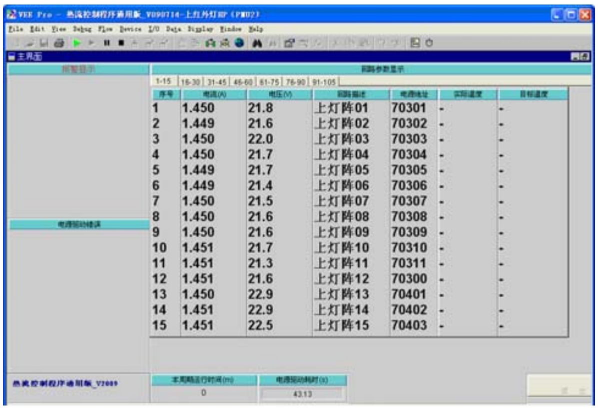

Fig. 4 Heat flux control software

Measurement and Monitoring System (MMS) is the key system used for test measuring and monitoring. During tests, MMS offers real-time and historical test data management. Satellite thermal test involved hundreds thermocouples and thermistors. Client stations allow test personnel to monitor temperatures of spacecraft, MBR and heat sink during testing. Screen options allow the selection and display of data as spreadsheets, live charts and other customized displays. MMS allows alarm setting during tests which can contribute to assist test personnel. MMS also acts as the central data logging system. The system permits storage, backup and distribution of test data from one central server.

VIII. Test Results

Lots of satellite thermal vacuum and thermal balance tests were successfully and efficiently completed using the advanced infrared simulation technology and facility thermal systems. The use of lamps during the thermal vacuum phases of the test was effective in quickly reaching and maintaining hot temperature plateaus. MBR response showed good repeatability which was demonstrated with the repetitive values measured during satellite thermal vacuum testing (see figure 5).

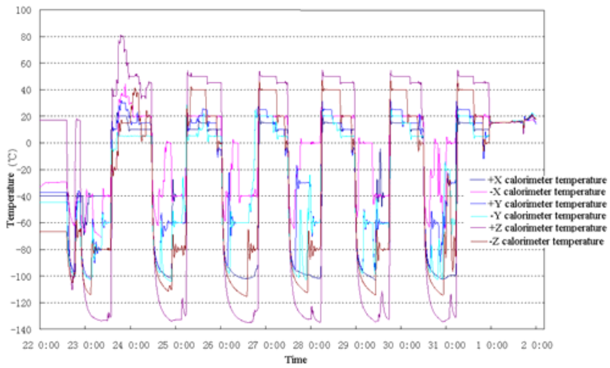

Fig. 5 Radiometer temperature values during thermal vacuum test

IX. Conclusion

BISEE now has an enhanced ability to execute thermal balance and thermal vacuum tests using infrared lamp technique. This advanced technology led to a more automatic, flexible and precise heat flux control during satellite thermal testing. The infrared lamp array designed in this work satisfies the requirement of test. The new test technology allow quicker test setups, simpler test design, better measurement accuracies and lower implementation costs. Overall, the new IR technology used during satellite thermal testing has proven to be successful and a valuable test method for China spacecraft thermal test.

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