Infrared lamp array design and radiation heat flux analysis

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Abstract: - A method is developed for predicting the radiant heat flux distribution produced by tungsten filament, tubular fused-quartz envelope heating systems. The method is an application of Monte Carlo simulation. Each infrared lamp is considered to be composed of two sources, the filament and the quartz envelope (tube).The filament is the primary source, while the quartz envelope is the secondary source, acquiring the bulk of its energy via absorption of energy radiated from the filament.

On this basis, Philips infrared lamp is used in the lamp array design and the calculation for the heat flux distribution reaching the target surface. We also calculate a variety of heat flux distribution reaching the target surface from different arrangements for the lamp array, which can be used in comparative analysis. The results show that appropriate adjustments of the array arrangement and thermo-physical parameters of reflective planes can significantly improve the uniformity of the lamp array.

Key-Words: - infrared lamp array;Monte Carlo;heat flux distribution;numerical simulation; thermo-physical parameter

1 Introduction

Quartz heating systems(infrared lamp) involving reflectors have been in use for approximately 35 years[1]. With the development of China's aerospace industry, the transient radiant heat flux simulation shows its increasing importance. Because of many advantages such as a fast response, the small shielding coefficient to spacecraft, the flexible installation, versatile, and the non-contact heating, infrared lamp is an ideal infrared source in the transient radiant heat flux simulation, so the infrared lamp will play an important role in space Thermal Vacuum Test.

Based on the characteristics of infrared lamp, using Monte Carlo method, a single infrared lamp model is established, and the radiant heat flux distribution reaching the target surface from this single lamp is also calculated. On this basis, the infrared lamp array is designed, and the radiant heat flux distribution reaching the target surface from this array is calculated.

2 Infrared single-lamp model and simulation of heat flux

2.1 Infrared single-lamp model program

Previous work was done to predict the radiant heat flux produced on a planar surface by a single tubular quartz heater with and without the effects of reflectors [2-4].

The natural particle for simulation of thermal radiation is a photon. However, the energy of a photon depends upon its wavelength. In order to avoid this complication, a photon bundle is chosen as the “model particle.” Thus, each photon bundle comprises a varying number of photons of the particular wavelength, in order to produce a standard unit of energy for each photon bundle. In practice, this clarication becomes transparent, but it does introduce the basic modeling considerations in a consistent manner. It is noted that the term photon bundle will be designated simply as bundle or energy bundle throughout the following discussions.

Energy bundles are “emitted” at random from heated surfaces in the simulation model. Using random numbers, a surface location for energy emission can be selected, and then another random number can be used to assign a wavelength. Subsequently, random numbers can be used to assign a direction of departure for the energy bundle. By incorporating distribution functions, uniformly distributed random numbers can be “mapped” into non-uniform distributions to model realistic physical processes.

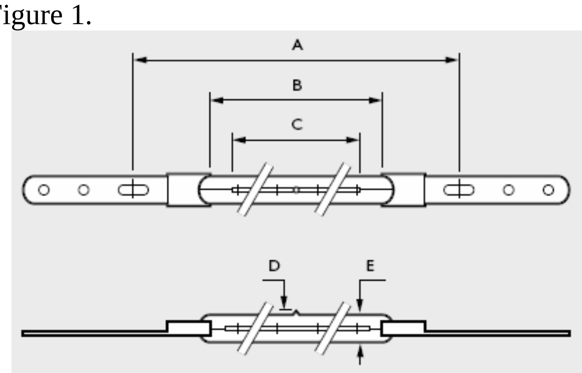
Furthermore, by tracing the path of the emitted energy bundle, additional random numbers can be used to approximate transmission, reection, or absorption when the path of the energy bundle intersects a surface. By developing appropriate distribution functions, the complete process can be simulated by repeated use of the technique [5,6].

Monte Carlo simulations utilize probability distribution functions to model complex physical phenomena by mapping a uniformly distributed random variable into appropriate non-uniform distributions representing the physical phenomena. By modeling all aspects of a complex physical process in this manner, it is possible to simulate the process. However, since the Monte Carlo simulation replaces classical analytical techniques with probabilistic results, a large population of simulation trials must be produced to yield distribution results that converge toward the actual physical system.

Each lamp is considered to be composed of two sources, the filament and the quartz envelope (tube).The filament is the primary source, while the quartz envelope is the secondary source, acquiring the bulk of its energy via absorption of energy radiated from the filament. It is necessary to differentiate between sources, since most systems are sensitive to source size and the distribution of energy between these sources. As a result of the multiple source model, the filament and the quartz envelope interact with each other as well as with the rest of the system. The quartz is treated as a participating medium with specular interfaces and spectral, directional interface properties. However, it is assumed that scattering, birefringence, and polarization associated with the quartz are negligible. All other materials in the system are treated as opaque surfaces. The filament is treated as a diffuse emitter-reflector. Spectral properties of the metallic reflector surfaces are incorporated where available.

2.2 Philips infrared lamp modeling

We will introduce you a frequently-used infrared lamp produced by Philips, and its size is shown in Figure 1.



Type	A	B	C	D	E
13169x/98	241 ±10	165	142 ±5	0	11.0

Fig.1 Philips IR lamp outline dimension chart

A reflective layer is increased in the half-circle of the tube (see fig. 2), and the light intensity distribution is shown in figure 3.

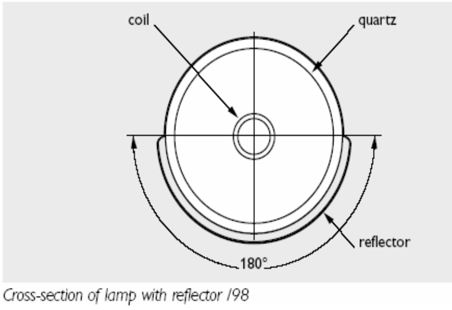


Fig.2 IR lamp outer coat sketch distribution chart

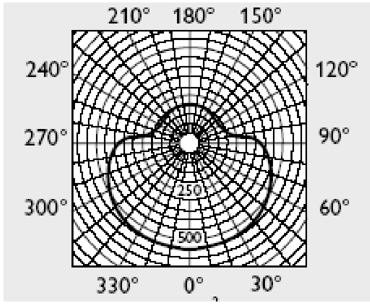


Fig.3 IR lamp light intensity

The target surface is a blackbody plane, which dimensions are 2.2m by 2.0m. The single lamp is 350mm above the target surface. By calculating, the heat flux distribution reaching the target surface is shown in figure 4.

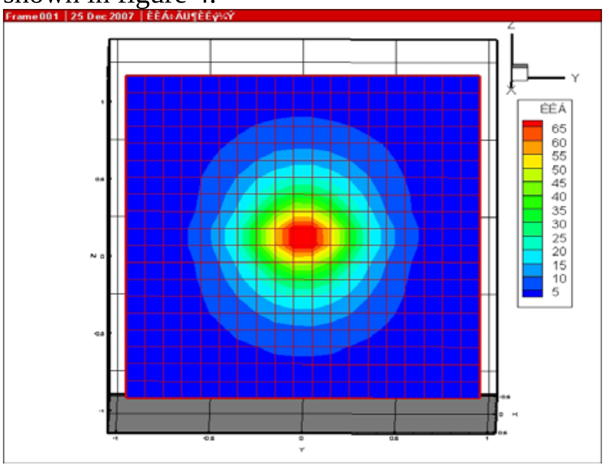


Fig.4 IR lamp radiant heat flux distribution chart

3 Infrared lamp array design and radiation heat flux distribution calculation

3.1 Infrared lamp array design tools

We developed an infrared lamp array design software. In this software, users can easily customize infrared lamp single models with different geometric and thermo-physical parameters. The customized models can be preserved in the model library for the convenience of using later. With the single-lamp model created, the user can arrange infrared lamp array. You can set its shape, size, arrangement manner, reflective plane parameters, etc., and you can also drag and drop a single lamp to make some partial adjustments. Figure 5 is an example designing lamp array in the software.

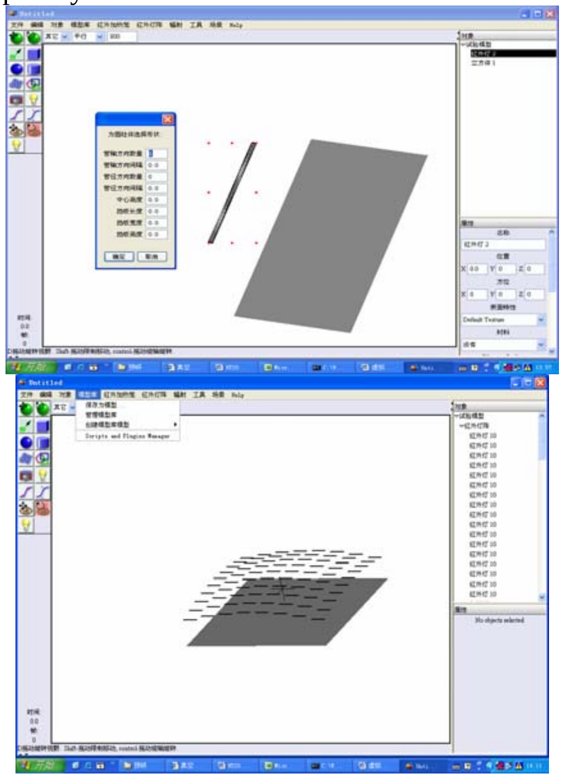


Fig.5 Lamp array design sketch in IR lamp array design software

3.2 Infrared lamp array heat flux distribution calculation

Lamp array is designed using Philips infrared lamp described in 2.2, and the array contains a total of 48 lamps. Effective radiation area of the lamp array is 2300mm by 2500mm, and the target surface is a blackbody plane, which dimensions are 2150mm by 2350mm. The lamp array is 350mm above the target plane. The power of each lamp is 60W, and the total power of the lamp array is 2880W. If there are reflective planes, the bottom edge of the planes is 50mm above the target surface. Several cases of the following are calculated.

1) All the lamps are at the same level without reflective planes.

By calculating, non-uniform degree of the lamp array is 19.3%, and the total heat flux reaching the target surface is 994.6W (see fig. 6 and 7).

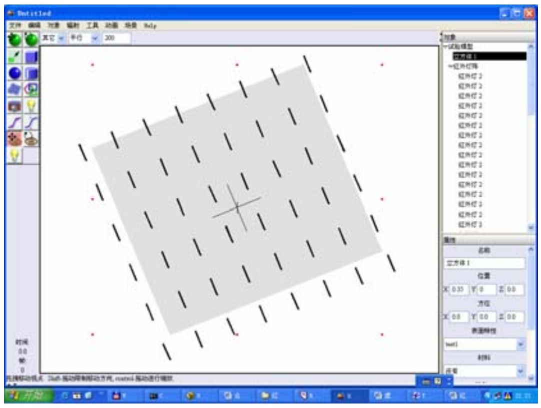


Fig.6 All the lamps at the same level without reflective planes.

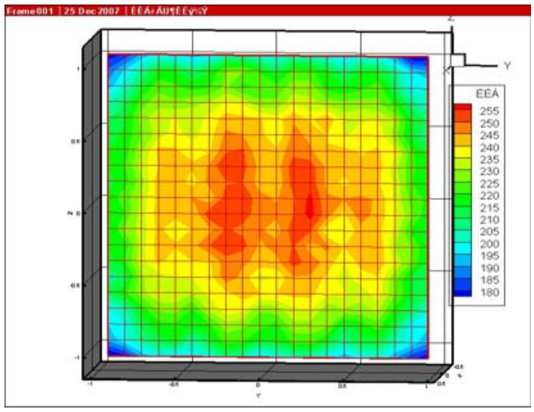


Fig.7 Heat flux distribution at the target surface.

2) Lamp heights are distributed by spherical function without reflective planes.

The lamps at the array center are the farthest away from target surface with 500mm, and the lamps at the array edge are the nearest away from target surface with 350mm. By calculating, non-uniform degree of the lamp array is 13.3%, and the total heat flux reaching the target surface is 903.8W (see fig. 8 and 9).

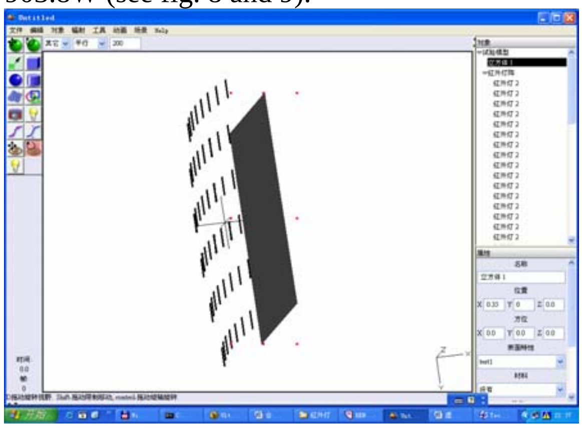


Fig.8 Lamps with spherical distribution without reflective planes.

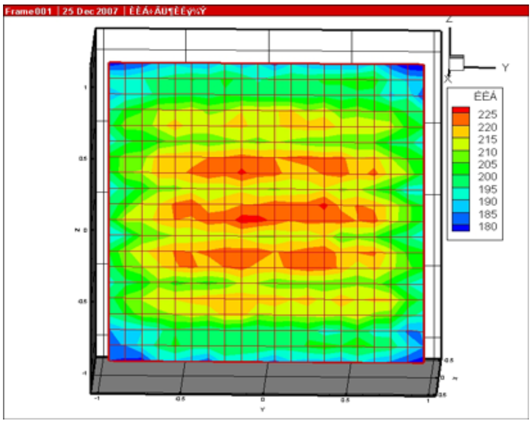


Fig.9 Heat flux distribution for situation 2.

3) All lamps are at the same level with stainless steel reflective planes.

The reflectivity of stainless steel reflective planes is 0.5, and it is specular reflection. By calculating, non-uniform degree of the lamp array is 14.4%, and the total heat flux reaching the target surface is 1275.8W (see fig. 10 and 11).

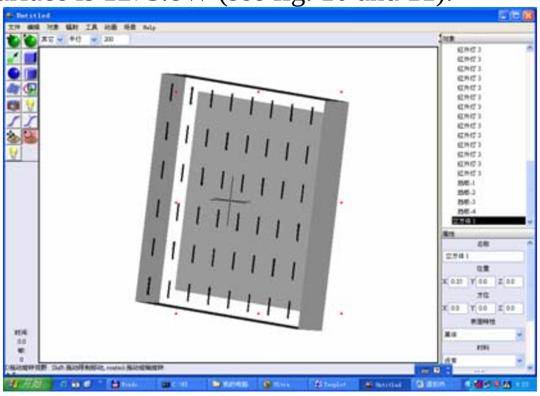


Fig.10 Lamps with spherical distribution with stainless steel reflective planes.

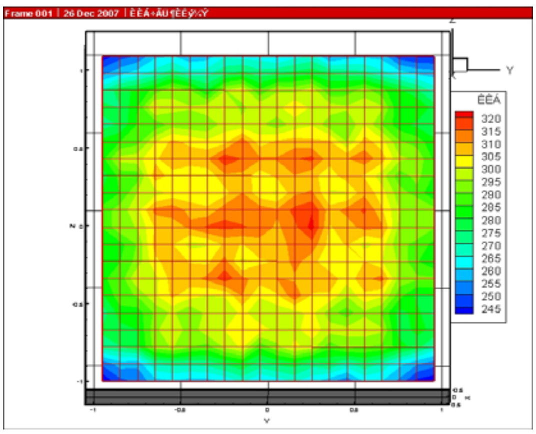


Fig.11 Heat flux distribution for situation 3.

4) All lamps are at the same level with gold-plated reflective planes.

Compared to the situation 3, the only change is using gold-plated reflective planes instead of stainless steel ones. The reflectivity of gold-plated reflective planes is 0.96, and it is specular reflection. By calculating, non-uniform degree of the lamp array is 7.8%, and the total heat flux reaching the target surface is 1485.6W (see fig. 12).

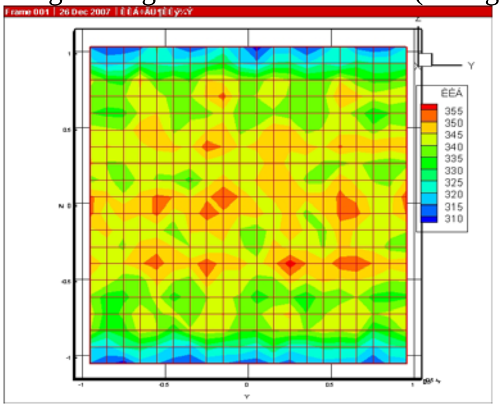


Fig.12 Heat flux distribution for situation 4.

5) Lamp heights are distributed by spherical function with gold-plated reflective planes.

The same reflective planes as mentioned in situation 4, and lamp heights are distributed by spherical function. The lamps at the array center are the farthest away from target surface with 450mm, and the lamps at the array edge are the nearest away from target surface with 350mm. By calculating, non-uniform degree of the lamp array is 7%, and the total heat flux reaching the target surface is 1433.9W (see fig. 13 and 14).

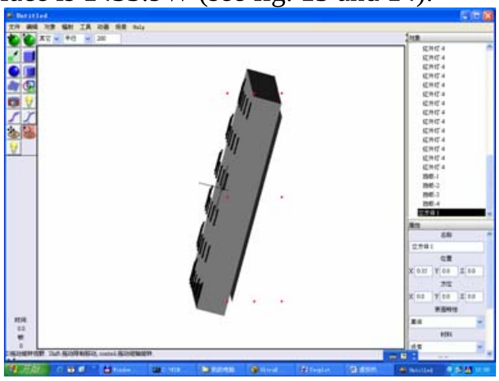


Fig.13 Lamps with spherical distribution with gold-plated reflective planes.

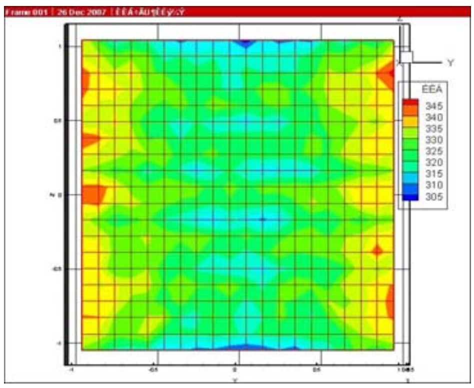


Fig.14 Heat flux distribution for situation 5.

3.3 Analysis of calculation results

According to the calculation of five kinds of situations, we can find that the uniformity of the lamp array is relatively poor without reflective planes. You can adjust the spacing among the lamps and height of single-lamp to improve. The energy utilization is also not high, and the heat flux reaching the target surface is below 1000W. After using stainless steel reflective planes, the uniformity of the lamp array is improved, and the energy utilization has also been greatly improved. After replacing the stainless steel reflective planes with gold-plated ones, the light array uniformity is greatly improved, and non-uniform degree of the lamp array is less than 8%. Then adjust the heights of lamps (see fig. 10), although the heat flux uniformity is not significant improvement, but high heat flux can be found concentrated in the edge of target surface, and uniformity in the middle is better, which provides a train of thought for the next step.

There are still some problems in enhancement of the reflectivity of reflective planes technology. Next our main work is to improve the uniformity of lamp arrays by optimizing the arrangement of arrays on the basis of existing conditions. Optimization for uniformity of lamp arrays is a very complex subject, which involves many parameters. If the means of pure mathematics is used to solve optimization, it will be very difficult. We will integrate it with the physical model. In addition, calculation accuracy of Monte Carlo method depends on the number of the particles emitted by the lamp model, and with more particles emitted, the accuracy is higher, but also time-consuming of calculation is longer. Thousands of times the calculation may be designed to optimize the lamp array, so it is necessary to take into account semi-empirical formula for quick calculation according to the existing Monte Carlo modeling.

4 Conclusion

In this paper, a method is developed for predicting the radiant heat flux distribution produced by tungsten filament, tubular fused-quartz envelope heating systems. The method is an application of Monte Carlo simulation, which takes the form of a random walk or ray tracing scheme. Experiments were conducted to study these quartz systems and to acquire measurements of the corresponding with analysis. Comparisions of the experimental results with analysis are presents and discussed. Good agreement between the experimental and simulated results was obtained. On this basis, Philips infrared lamp is used in the lamp array design and the calculation for the heat flux distribution reaching the target surface. We also calculate a variety of heat flux distribution reaching the target surface from different arrangements for the lamp array, which can be used in comparative analysis.

Next, Philips lamp model will be modified by compared with the actual test results, so further guidance can be given to lamp array design in tests.

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