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Numerical thermal mathematical model correlation to thermal balance test using adaptive particle swarm optimization (APSO)

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ABSTRACT

We present structural and thermal model (STM) tests of the BepiColombo laser altimeter (BELA) receiver baffle with emphasis on the correlation of the data with a thermal mathematical model. The test unit is a part of the thermal and optical protection of the BELA instrument being tested under infrared and solar irradiation at the University of Bern. An iterative optimization method known as particle swarm optimization has been adapted to adjust the model parameters, mainly the linear conductivity, in such a way that model and test results match. The thermal model reproduces the thermal tests to an accuracy of 4.2 °C ± 3.2 °C in a temperature range of 200 °C after using only 600 iteration steps of the correlation algorithm. The use of this method brings major benefits to the accuracy of the results as well as to the computational time required for the correlation.

1. Introduction

The European Space Agency's BepiColombo spacecraft mission to Mercury is scheduled to launch in 2014 [1]. The instruments and the spacecraft have to withstand a high input solar flux (up to 10 times that seen at the Earth). The designs have required careful study and detailed thermal modeling and testing to demonstrate feasibility and performance under this thermal load.

Generally thermal model correlation, i.e. the adaption of model parameters, to measurements is very time consuming. It requires good knowledge of the thermal system and a lot of manual work to obtain accurate solutions. We have been investigating approaches with the goal of reducing not only this work, but also obtaining more accurate solutions in a smaller computation time via an automated correlation method. If done manually the correlation accuracy usually scales with time. So increasing the calculation density in time will lead to more accurate solutions in the same working time.

To achieve our goal we have adapted the so-called Particle Swarm Optimization (PSO) method to our thermal model correlation problem. PSO belongs to the family of genetic algorithms and simulates social behavior. It has been originally attributed to Kennedy, Eberhard and Shi [2] [3],. A slightly different version, called Adaptive Particle Swarm Optimization (APSO) [4], has been applied here.

The method has been applied to the correlation of the BepiColombo laser altimeter (BELA) receiver baffle structural and thermal model (STM). Thermal balance tests have been carried out at the University of Bern (UBE) taking advantage of the newly established solar simulator [5] which is housed in UBE's thermal vacuum chamber. The reflective Stavroudis baffle of BELA has been modelled and tested as described in [6] [7], and [8].

In section 2 the theoretical part of the applied APSO is described while in section 3 the thermal balance tests are described. Section 4 describes the thermal mathematical models which have been correlated. In section 5 it is described how the APSO is implemented while in section 6 the solution is presented. The effectiveness of the approach and the conclusions are presented in section 7 and 8.

2. Theory

The subject of optimization is a fitness function defined in a multidimensional search space ($f : \mathbb{R}^D \rightarrow \mathbb{R}$). The swarm consists of several particles X_i, each representing a possible solution to the optimization problem, where $X_i = [x_i^1, x_i^2, x_i^3 \ldots x_i^D]$ is a D-dimensional array containing all the parameters of the problem. The quality or fitness of a solution candidate is then calculated from the corresponding fitness function $f(X_i)$ and is represented as single number. The goal of the optimization process is to minimize this

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