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PROBABILISTIC PERFORMANCES ASSESSMENT FOR PHASE-CHANGE MATERIALS AIDED SINGLE-PHASE MECHANICALLY PUMPED FLUID LOOPS

Abstract

With the aid of Phase-Change Materials (PCMs), the performances of single-phase Mechanically Pumped Fluid Loops (MPFL) could be improved, including temperature stability and thermal-design mass or power, if the heat dissipation characteristics of payloads are suitable. However, heat dissipation characteristics are being affected by uncertainty sources considering the increasingly complex space thermal management applications. In order to quantitatively assess the MPFL performances under uncertainty conditions, probabilistic approaches are proposed in this paper.

In this study, PCM is integrated into MPFL cold plates, and transfers heat from the payloads to the heat transport fluid in the cold plates. Payloads having periodic heat dissipation pulses are considered here and the magnitudes and the duty cycles of the pulses are modeled as random variables. To satisfy the payloads temperature requirements, flow rates of the heat transport fluid are controlled by adjusting the pump rotating speeds. In order to assess the MPFL performances, e.g., payload temperature variations, a flow and heat-transfer lumped-parameter system model is established which includes PCM part, cold plates, pumps, radiators, pipes and other function blocks. Control algorithms are also integrated to control flow rates and fluid temperatures. Thanks to the effects of PCM, flow rates of the heat transport fluid could be reduced compared with those without PCM. Furthermore, thermal-design mass and power could also be estimated based on the flow and heat transfer parameters and engineering experiences.

Monte Carlo method is employed to capture the probability characteristics of the MPFL performances. First samples are generated for the random variables used in the system model according to the distribution definitions. Then those samples are used as model inputs and the corresponding performances would be obtained by running the system model. Finally probability characteristics of the performances are calculated by statistics processes.

The results reveal that the random payloads would result in uncertain performances, whose probability distributions could also be obtained simultaneously by using the approaches and corresponding methods proposed here. Furthermore, by changing design parameters, e.g., PCM mass, variations of the performance probability characteristics could also be studied. Based on the results, benefits of PCM could be assessed quantitatively by taking into account the uncertainty of the payloads.