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Thermodynamic Operating Temperature Control of a Loop Heat Pipe

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Extended Abstract

In this work, a method for a thermodynamic operating temperature control of the loop heat pipes (LHPs) was proposed to achieve a precise, stable, and theoretically predictable operating temperature control. To this end, a pressure controlled LHP was devised to control the thermodynamic saturation state of the evaporator by applying hydraulic action on the compensation chamber with an immiscible control gas. In particular, by employing the structure of the LHP-based isothermal region generator, it was attempted to control the temperature of the isothermal region, and the resulting operating temperature controllability was investigated in terms of stability, precision, and predictability. Theoretical basis and limitations of the proposed method were established based on the thermodynamic operating principles of the LHPs, and the experimental validation was performed. Dowtherm A was chosen as the working fluid for higher operating temperature, and helium as the control gas due to its light weight compared to the working fluid.

Test results showed that the operating temperature control of the LHP-based IRG was achieved by applying the hydraulic action on the compensation chamber. The stability of the controlled isothermal region temperature was 25 mK, and the resolution of the temperature control was around 60 mK at 100 Pa increase of the control gas. Under the moderate pressure change of the control gas, the isothermal region temperature showed instantaneous and stable changes, and the controlled isothermal region temperature was satisfactorily predicted by the thermodynamic relations. The proposed thermodynamic temperature control was expected to have two limitations on the control gas pressure increase and decrease, respectively. However, only the limitation on the pressure increment manifested itself as a temporary operation failure for the excessive control gas pressure increase. Even though an operation failure occurred at the excessive pressure increase of the control gas, the pressure controlled LHP soon recovered to a new stable state, and the recovered state followed the theoretically predicted state accurately. Therefore, it was suggested that a large scale temperature increase with large control gas pressure increments followed by a precise temperature control with small pressure increments was an effective way of achieving the precise temperature increase to a target value if the temporary instability was acceptable.

The temperature uniformity of the isothermal region was improved with the increasing control gas pressure due to the increased vapor speed at the increased vapor temperature. The absolute value in the temperature uniformity ranged from 0.19 °C to 0.29 °C at the distance of 25 cm from the bottom and at the minimum start-up heat load of 800 W. The thermal stability of the working fluid (Dowtherm A) restricted the higher heat load operation and thus limited the temperature uniformity enhancement of the isothermal region. Therefore, another thermally stable working fluid at higher heat loads was required to attain high degree of the temperature uniformity.