Numerical Study for Improvement of Startup Characteristics of Oscillating Heat Pipe with Check Valves

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Abstract

This paper presents the numerical study for improvement of startup characteristics of Oscillating Heat Pipes(OHP). Our previous study suggested that the OHP has the difficulty to start up when liquid phase localizes in the cooling section. In this study, several methods for improving OHP startup are investigated using numerical analysis. As a first step, we suggested changing the position of the check valve as a way to improve a startup characteristics. As a result of the numerical analysis, startup characteristics of OHP could be improved by changing the positions of check valves.

Keywords: Oscillating Heat Pipe; Startup; Check Valve; Numerical Analysis

An Oscillating Heat Pipe (OHP), also known as a Pulsating Heat Pipe (PHP), is a thermal control device using vapor-liquid two-phase flow [1,2]. An OHP consists of only bended capillary tubes with a heating section and a cooling section at each end. An OHP is charged with a working fluid to almost 40–60% of its internal volume. The working fluid distributes separately as vapor plugs and liquid slugs along the flow path because of the strong capillary force in mini channels. Once heat is applied to the heating section, oscillation of liquid slugs is excited by the pressure difference between each channel [3]. This way, the working fluid transports heat from the heating section to the cooling section by latent heat and sensible heat. As merits of using OHPs, it is quite thin. Therefore, an OHP can transport heat from very narrow spaces with high efficiency. In addition, because OHPs do not have wick structure, its configuration is a very simple flat-plate shape, and they are much lighter than conventional heat pipes. As a result of these advantages, OHPs have become very attractive as thermal control devices for spacecraft with high heat dissipation.

The Oscillating Heat Pipe with check valves (CVOHP) is a promising next-generation heat transport device for spacecraft because of its several excellent features. Fig. 1 is the schematic of CVOHP.

Japan Aerospace Exploration Agency (JAXA) has developed a Flat-plate Heat Pipe by applying the conventional OHP [4]. A CVOHP has check valves in the middle section, and pipes are held between metal plates. By installing check valves in the flow path, the thermal performance is improved significantly. The CVOHP was demonstrated in space environment by using the small satellite named SDS-4 of JAXA. The on-orbit experiment project is called "FOX" (Flat-plate Heat Pipe on-Orbit eXperiment). The aim of the experiment was to confirm the performance of CVOHP in a microgravity environment. In the on-orbit experiment, the CVOHP had showed good thermal performance for almost four years [5]. From this experiment, it was found that the performance of CVOHP in microgravity does not differ from that it in terrestrial gravitational condition because the thermal conductivity maintained the same values. However, the CVOHP did not start up smoothly in several heating timing conditions. Because it was found that CVOHP tended not to start up after the eclipse, the initial vapor-liquid distribution was considered as the reason of start-up trouble. The temperature of the satellite panel used as the cooling section decreased during the eclipse, and liquid slugs could move from the heating section and localize in the cooling section. To confirm this expected phenomenon, the numerical simulation had been performed.

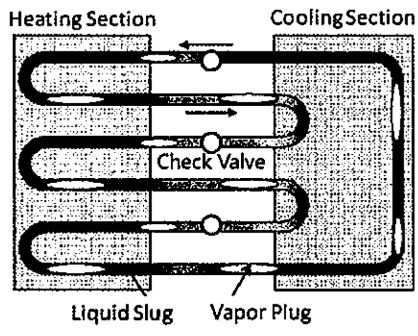


Fig. 1. Schematic of CVOHP

Daimaru et al. developed the practical one-dimensional numerical model of CVOHP to simulate the vapor-liquid distribution in the on-orbit experiment. From the numerical results, it revealed that the localization of liquid slugs in the cooling section results in CVOHP startup difficulty shown in Fig.2. Conversely, the CVOHP can start when liquid slugs exist in the heating section. These results are congruent with expected phenomena from the on-orbit experiment. Therefore, the study for improvement of start-up characteristics of OHP is necessary for space application, which requires robustness for the system.

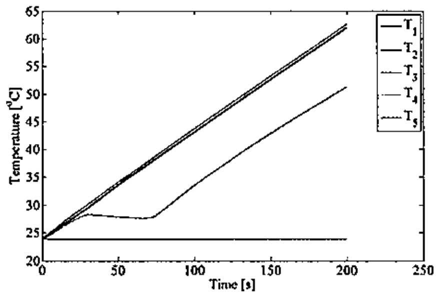


Fig. 2. Effects of Initial Vapor-Liquid Distribution on Start-up Characteristics.

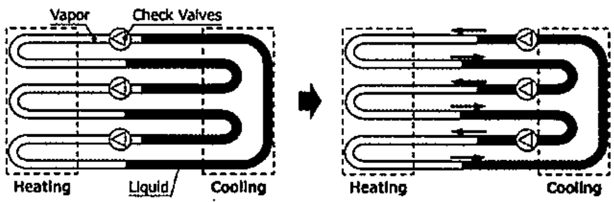
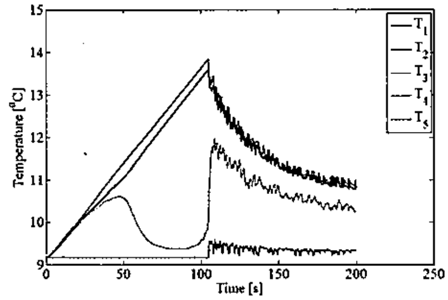


Fig.3. Conceptual Diagram of Improvement of Start-up Characteristics.

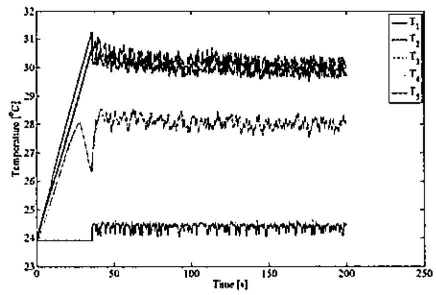
Based on this background, we decided to investigate the method for reliable startup of OHP by numerical simulation. As a first step, we changed the position of the check valve shown in Fig.3. Because tiny fluctuations of positions of liquid slugs had been observed even in the case of localization of liquid slugs in the cooling section [6], it is possible to develop the flow from the tiny oscillation to the circulation flow by causing a disturbance using check valves.

Figure 4 shows the temperature history result obtained by changing the position of check valve. From this result, the CVOHP succeeded to start-up in lower and higher heat input cases. Thus, it can be said that the start-up characteristics of CVOHP can be improved by changing positions of check valves.

This result is the first step. For a reliable startup, there are still several ways to think about. For example, even if the liquid is unevenly distributed in the condensation section, since the liquid film exists in the heating part, it is possible to change the characteristics of the pipe wall surface (such as cavity radius, hydrophobic/hydrophilic) so as to reliably boil and consider a method of eliminating uneven distribution of the liquid. In the future, we plan to carry out calculations with such a view in mind.



(a) Heat Input 2.6 W



(b) Heat Input 11.1 W

Fig.4. Temperature history result obtained by changing the position of check valve.

REFERENCES

[1] Akachi, H., Polasek, F., and Stulc, P., "Pulsating Heat Pipes," *Proceedings of the 5th International Heat Pipe Symposium*, Melbourne, Australia, 1996, pp. 208-217.

[2] Daimaru, T., and Nagai, H., "Operational Characteristics of the Oscillating Heat Pipe with Noncondensable Gas," *Journal of Thermophysics and Heat Transfer*, Vol. 29, No. 3, 2015, pp. 563-571.

[3] Daimaru, T., Yoshida, S., and Nagai, H., "Study on Thermal Cycle in Oscillating Heat Pipe by Numerical Analysis," *Applied Thermal Engineering,* Vol.113 (25), 2017, pp. 1219-1227.

[4] Maeda, M., Okamoto, A., Kawasaki, H., and Sugita, H., "Development of Flat Plate Heat Pipe and the Project of On-orbit Experiment," *Proceedings of the 41st International Conference on Environmental Systems*, Portland, U.S., 2011, AIAA 2011-5142.

[5] Okamoto, A., Ando, M., and Sugita, H., "Initial Evaluation of On-orbit Experiment of Flat-Plate Heat Pipe," *Proceedings of the 17th International Heat Pipe Conference*, Kanpur, India, 2013.

[6] Daimaru, T., Nagai, H., Ando, M., Tanaka, K., Okamoto, A., and Sugita H., "Comparison between numerical simulation and on-orbit experiment of oscillating heat pipes," *International Journal of Heat and Mass Transfer*, Vol. 109, 2017, pp.791-806.