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Experimental Thermal and Fluid Science 32 (2008) 939–946
Experimental Thermal and Fluid Science
www.elsevier.com/locate/etfs

Experimental investigation on startup of a novel two-phase cooling loop

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Received 19 September 2007; received in revised form 29 October 2007; accepted 30 October 2007

Abstract

The startup of a two-phase cooling system is a complex transient phenomenon, especially for the mechanically pumped two-phase cooling loop (MPCL), which is a promising thermal control method for extracting heat from large electronic equipments efficiently. In this paper, the system design and work principle as well as the test setup of an MPCL are presented and the startup processes of the MPCL are studied. The experiments on the startup processes under variety of conditions were carried out. Special attention has been paid to the startups of the system in different evaporative temperature, various mass flow or heating load and some abnormal startup prehistory. The transient flow exchange between the main loop and accumulator was observed and discussed according to different startup sections, which have been identified as pre-condition, pump startup and heat load startup. During the startup processes, the system presents a good stability and each part of the system performs a reasonable temperature wave, except some superheat phenomena in the evaporator. The superheat is mainly related to evaporative temperature and the initial liquid distribution in the evaporator. In general, the lower the evaporative temperature is, the higher superheat occurs. In conclusion, the startup processes in different situations may cause some liquid superheats and evaporator temperature overshoots, but they will not affect much on the steady state operation of the MPCL.

Keywords: Two-phase; Mechanically pumped; Startup; Superheat

1. Introduction

Heat transfer via phase change of working fluid rather than specific heat capacity was a major thermal control technology applied in the last decade. The applications mainly include heat pipes, capillary pumped loops (CPLs), loop heat pipes (LHPs), and the novelist space thermal control technology, mechanical pumped cooling loops (MPCL). As a kind of two-phase device, CPL/LHP or MPCL can provide a very stable and even temperature profile regardless of the change in the heat load and/or heat sink condition. While CPL and LHP have been the major thermal control innovations in the last decade and reached a stone of flight maturity by offering major advantages [1,2], both of them have a single evaporator with an outer diameter (O.D.) of more than 10 mm and a length of less than 10 m. Several LHPs with a single 15 mm or 7 mm O.D. evaporator have been built and ground tested [3–5]. In operation, the most difficult issues are in the startup of the systems, and it is also the main problem needed to be solved for applications in engineering. For instance, the start-up of LHP is often a complicated task, and it is needed to take into account a lot of factors, such as the initial states of the working fluid across the primary wick in the evaporator, the elements geometry structure, and the ambient conditions of the system [6–11]. As a novel cooling technology, the mechanically pumped two-phase cooling loop has shown much predomination characteristics and been designed for many years [12,13], however, it is lack of reports on the experimental investigation about this system in public paper, especially for the study on the

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doi:10.1016/j.expthermflusci.2007.10.010

processes of startup. In this study, the experiments on the startup processes under variety of conditions are carried out to reveal the behaviors of startup of MPCL in different evaporative temperatures, variable mass flow or heating load and some abnormal startup prehistory. The transient flow exchange between the main loop and accumulator has also been investigated according to different startup patterns, which are identified as pre-condition, pump startup and heat load startup.

2. Considerations in design

Fig. 1 shows the schematic diagram in which the MPCL conception is realized. Besides heat rejection, it allows a wide variety of different design embodiments and, at the same time, extends considerably the sphere of functional potentialities of two-phase heat-transfer devices with pumping of working fluid. Basically, the MPCL system consists of an evaporator, two condensers, a heat exchanger, an accumulator, a mechanical pump and connecting pipes.

The heat is absorbed in the evaporator and released from the condensers. A mechanical pump drives the working fluid circulating in the whole loop continuously. In order to avoid cavitation erosion and guarantee the pure liquid operated in the pump, the pump is located behind the condensers which possess an overcapacity, not only for condensing the whole vapor but also providing at least a few degrees of sub-cooling of the liquid. For the sake of reducing the pre-heater consumption, a heat exchanger is employed to connect the inlet and outlet pipes of the evaporator together for heat recovery. In this way, the absorbed heat from the evaporator can be used to heat the entering evaporator sub-cooled liquid from the pump and to let the liquid temperature close to the two-phase evaporative temperature. A pre-heater is placed to heat fluid to the saturation point before entering the evaporator to ensure a uniform temperature along the entire evaporator, due to the phase change process will have little temperature gradient along the evaporator.

Normally, those electronic devices, i.e. heat source which need cooling by MPCL always have a permitted working temperature range. So, bad working conditions can be avoided by varying the set point of the evaporative temperature in the evaporator. For example, if condensers are running in a hotter orbit environment, the set point can be raised to a higher value to ensure the inlet of pump being sub-cooling liquid. If condensers are running in cold case, the set point can be lowered to avoid extreme sub-cooling and so as to reduce the power consumption of the pre-heater.

The evaporative temperature is controlled by an accumulator which is a small steel vessel with vapor and liquid inside. It is attached to the main loop by a small pipe to accommodate fluctuating fluid inventories and also to provide a source of constant pressure against the refrigerant, thus locking the loop at a constant temperature. Since the internal pressure of the whole loop is held constantly, evaporation occurs at a nearly constant saturation temperature that is almost the same degree as the accumulator if different pressure between accumulator and evaporator is negligible. Hence, the evaporation temperature control is typically accomplished by thermoelectrical coolers and heaters both of which are settled on the accumulator to regulate the temperature close to the desired "set point". The more stable temperature the accumulator has, the smaller temperature fluctuation will happen in the evaporator.

3. Experimental

Considering the issues about designing and testing MPCL for future space missions, an experimental setup is constructed according to the model proposed by

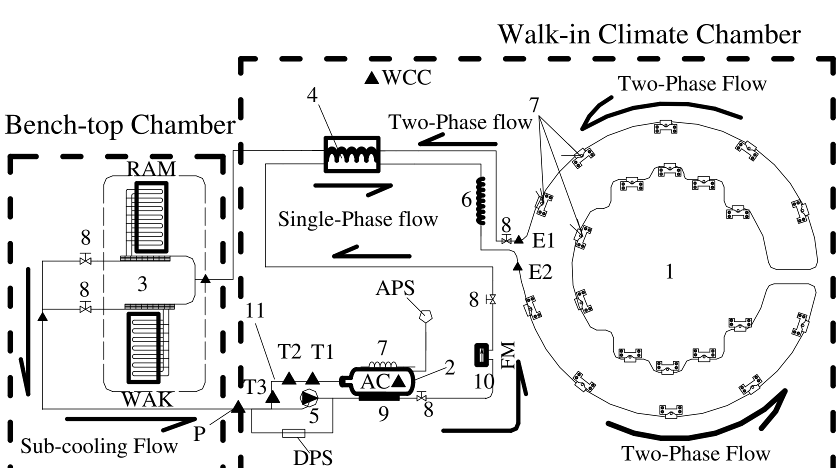

Fig. 1. The schematic diagram of the two-phase MPCL experimental system. (1: evaporator; 2: accumulator; 3: condensers; 4: heatexchanger, type:tube in tube; 5: pump; 6: pre-heater; 7: heater; 8: valve; 9: thermoelectric cooler; 10: mass flow meter) (FM: mass flow; APS: absolute pressure sensor; DPS: different pressure sensor; HL: heat load) ▲ thermocouples whose positions are as following: E1: evaporator inlet; E2: evaporator outlet; AC: accumulator; HS: heaters surface; P: pump inlet; WCC: walk-in climber chamber; T1, T2, T3: on the supply pipe).