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Physics Procedia 67 (2015) 551 – 556

Physics Procedia

25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014, ICEC 25–ICMC 2014

Design of a hydrogen pulsating heat pipe

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Abstract

In order to enhance the application of a cryocooler that provides cooling capacity at the cold head location, and effectively spread that cooling over an extended region, one requires an efficient heat transfer method. The pulsating heat pipe affords a highly effective heat transfer component that has been extensively researched at room temperature, but is recently being investigated for cryogenic applications. This paper describes the design. The experimental setup is designed to characterize the thermal performance of the PHP as a function of the applied heat, number of turns, filling ratio, inclination angle, and length of adiabatic section.

Keywords: Cryogenic Pulsating Heat Pipe; Design; Heat Leak; Structure Calculation; Cooldown calculation

1. Introduction

With the development of advanced technology such as superconducting technology and semiconductors, there are some limits for the application of cryocoolers that provide cooling only at the cold head location. For the applications of large-scale superconducting magnets, such as fusion devices and SMES, regenerative cryocoolers in particular are by themselves ineffective at distributing the cooling they produce [1]. In order to solve this problem, various groups are presently investigating a novel method which utilizes a highly efficient heat transfer component, the pulsating heat pipe. The pulsating heat pipe has drawn significant amount of attention over the past twenty years

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doi:10.1016/j.phpro.2015.06.074

Nomenclature

D	inner diameter	WF	working fluid
N	turn numbers	FR	filling ratio
β	inclination angle	ρ_l	working fluid density of the liquid phase
ρ_v	working fluid density of the vapour phase	m	mass
g	the acceleration of gravity	T	temperature
q_{in}	the input heat	q_{out}	the heat leaving
c_p	heat capacity		

The pulsating heat pipe (PHP) was first proposed by Akachi in the early 1990s [2]. It has a long capillary pipe bent into many turns, and is composed of a condenser section, adiabatic section and evaporator section. Due to the effect of capillary forces, the vapor slugs and liquid plugs forming in the capillary pipe after it is partially filled with the working fluid will transfer heat from the evaporator to the condenser section through self-oscillation and phase change. PHPs are similar to conventional heat pipes, with regard to their high conductivity and variable heat flux. However, they provide additional advantages such as a simple structure, low processing cost and insensitivity to gravity, benefits that have created a large amount of interest in their development.

The pulsating heat pipe affords a highly effective heat transfer component that has been extensively researched at room temperature, but is recently also being investigated for use in low temperature applications, which will be introduced carefully in the next section.

2. The research of cryogenic pulsating heat pipe

Cryogenic pulsating heat pipes typically utilize the cooling capacity from cryocoolers, rather than the usual liquid-circulation cooled condenser associated with room temperature applications. The cryogenic pulsating heat pipe therefore serves the crucial function of spreading cooling from the localized region of a cryocooler cold-head to the larger regions associated with cryogenic applications, such as a superconducting magnet.

The research to date on cryogenic pulsating heat pipes is summarized in table1. In the table1, β=90°means that the condenser section is above the evaporator section; β=0°means condenser section and the evaporator section are in the horizontal direction; β=-90°means evaporator section is above the condenser section. UM means University of Missouri; NIFS means National Institute for Fusion Science of Japan, UW-Madison means University of Wisconsin Madison.

Table1. The research summary of cryogenic pulsating heat pipe [3]-[9]

Institute	WF	Capillary pipe		N	FR（%）	Heat（W）	β(°)	Thermal conductivity（W/m·K）
		Material	D(mm)					
UM	N2	Cu	1.65	8	48	20.5~380.1	0	11600~26100
CEA-France	He	Cu-Ni	0.5	5	-	0.015~0.145	0~40	18700
NIFS	H2	SSL	0.78	5	31~80	0~1.2	90	500~3000
			1.58	5	50~72.2	0.588~16	-90~90	2220~11480 (0-90°)
	N2		0.78	5	17~70	0~7	90	5000~18000
	Ne		0.78	5	16~95	0~1.5	90	1000~8000
			1.58	5	50.6~86.1	0.588~16	-90~90	5100~19440 (0-90°)
UW-Madison	He	SSL	0.5	32	4~26.5	0.003~0.086	0	1800~2457