ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-MOPB105

THERMOSIPHON COOLING LOOPS FOR ARIEL CRYOMODULES

Yanyun Ma†, A. Koveshnikov, R.E. Laxdal, D. Lang, N. Muller,
TRIUMF, Vancouver, Canada

Abstract

Thermosiphon cooling loops have been used in ARIE [1,2] cryomodules for 1.3GHz superconducting cavities cooling. It can deliver 4K liquid Helium from 4K phase separator to cavity thermal intercepts and return the vaporized liquid to the 4K phase separator as a refrigerator load. The design and test results are presented in this paper.

INTRODUCTION

The ARIEL is an on-going project at TRIUMF which will triple TRIUMF's capability of rare isotope production over the next ten years for the needs of the international scientific community [3]. ARIEL uses a 50 MeV, 10 mA continuous-wave (CW) electron linear accelerator (e-Linac) as a driver accelerator utilizing superconducting bulk niobium technology at 1.3 GHz. The accelerator is divided into three cryomodules including a single cavity injector cryomodule (ICM) and two accelerating cryomodules (ACM) with two cavities each as shown in Fig. 1.

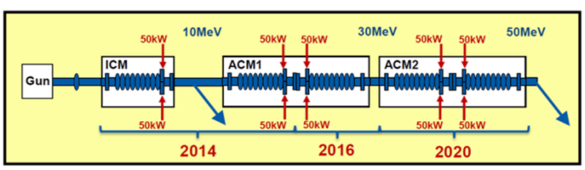


Figure 1: A schematic of the e-Linac showing the installation stages.

A first phase consisting of an ICM, and an accelerating cryomodule with just one accelerating cavity on board plus a `dummy' cavity that occupies the second cavity space in the cryomodule (ACMuno) was installed for initial technical and beam tests to 23 MeV in 2014 [4]. An upgrade that added a second 1.3 GHz nine-cell cavity to ACM1 is under testing [5,6]. The 2nd phase will add ACM2 module and a ramp up in beam intensity to the full 50 MeV, 0.5 MW capability.

The ARIEL cryomodule design, shown in Fig. 2, borrows significantly from the ISAC-II cryomodules. Each cryomodule is outfitted with an on-board 4K to 2K cryogenics insert [2,7]. The insert consists of a 4K phase separator, a 2.5gm/sec heat exchanger, a JT expansion valve and a 4K cooldown valve.

The 300 K to 4 K connections of cavities at the beam pipes and at the power couplers are intercepted at both 77 K and 4K. Piping within the cryomodule delivers the 4.2K Helium from phase separator to a number of 4K thermal intercepts and then returns the two phase He back to the 4K phase separator. Depending on the thermal load, the density mismatch between the liquid side(supply side) and the two-phase side (return side) can overcome the head pressure difference between supply and return pipes. In this case a mass flow will be initiated in the siphon loops and convective heat transfer will occur from the load to the helium.

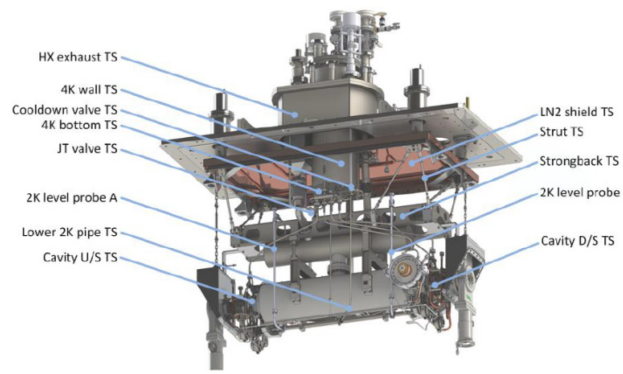


Figure 2: ICM assembly.

Thermosiphon loops were designed, tested and optimized at TRIUMF during the development of the 4 K/2 K cryogenic insert and the commissioning of cryomodule.

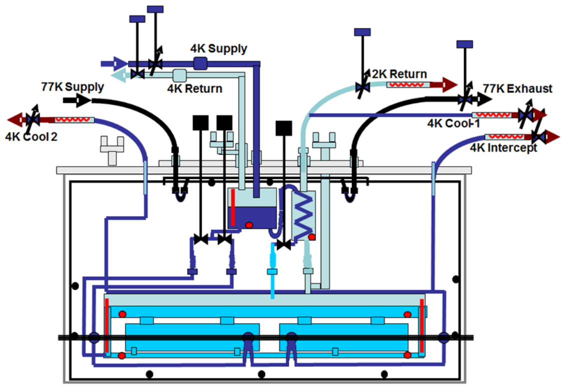
THERMOSIPHON DESIGN

The simple structure and higher cooling capacity make thermosiphon an attractive cooling method as shown in Fig. 3. The 4K thermal intercept circuit in Fig. 3 (a) is replaced by a supply line from the 4K reservoir to the heat loads with returning vapour returning to the upper part of the phase separator which shown in Fig. 3 (b). It is attractive since it reduces the liquefaction load on the refrigerator system and reduces the external piping, heaters and control valves as well. The thermosiphon supply pipe is started from the bottom of the 4K phase separator and divided to several pipes underneath the cold mass. There are four thermal intercepts for each cavity: two of them on the beam pipe flanges and the other two on the couplers. The 4K thermal intercepts are isolated with 77K thermal intercepts by bellows. The return pipes deliver the liquid Helium to the thermal intercepts. All the return pipes are connected together through a manifold and then connected to 4K phase separator.

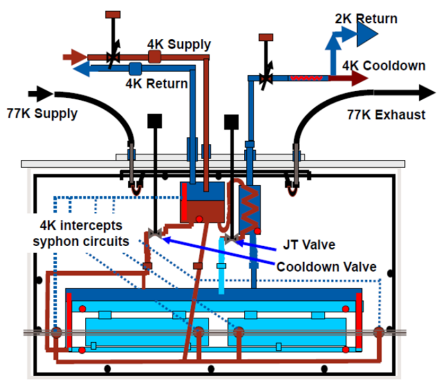
† mayanyun@triumf.ca

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-MOPB105



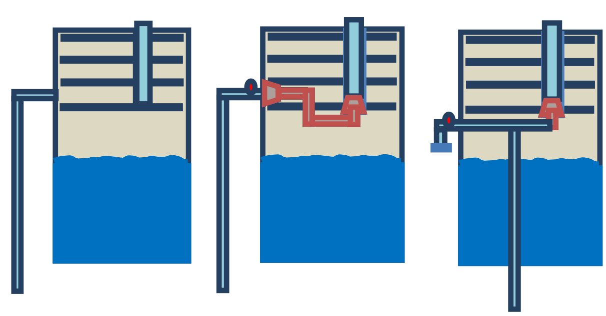
(a) ACM piping schematic without thermosiphon.



(b) ACM piping schematic with thermosiphon.

Figure 3: comparison between without and with thermosiphon

As a part of the 4 K/2 K cryogenic insert test, it was initially tested in a vertical cryostat with variable thermal loads. The tests gave early experience with the thermal siphon circuit [1]. In particular the study showed that the design of the siphon return is important. A schematic of various return methods for the siphon circuit are shown in Fig. 4.



(a) (b) (c)

Figure 4: (a) the initial return loop in 4K/2K insert test;(b) modified return loop with funnel (c) return loop pass through reservoir bottom.

In variant (a) the returning 2-phase flow can cause a high heat load in the 4 K phase separator if allowed to cause convective mixing in the vapour space while in (b) this mixing is minimized by funnelling the returning vapour to the helium return stinger which is shown in Fig. 5.

A third variant (c) passes the return vapour through the 4 K bath and a lower exhaust position than (a) and (b). The thermosiphon circuit in the cryomodule is tested by applying various heater levels to the siphon loads and measuring the rate of falling level in the 4 K reservoir with the J-T valve closed. Temperature sensors have been installed to monitor the siphon circuit mass flow in (b) and (c), shown in Fig. 4 as a red point. Both variants (b) and (c) have been used with (c) exhibiting favourable performance.

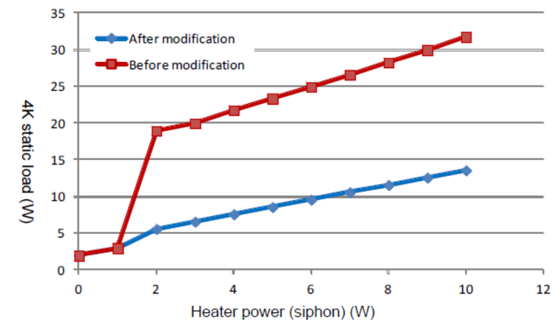


Figure 5: The performance comparison between difference return loop

THERMOSIPHON SIMULATION

CFD simulations of mass and heat transfer and the 2-phase flow has been done with ANSYS-Fluent. With a simple 'U' shape model which is shown in Fig. 6.

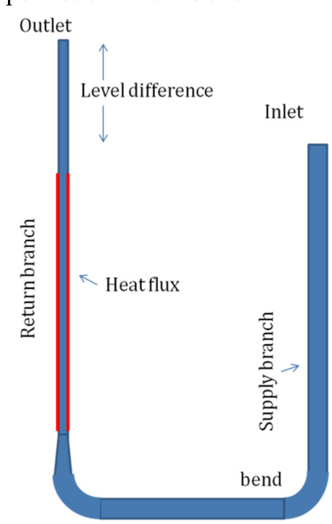


Figure 6: The 'U' shape model.

In order to compare the 'U' shape model simulation results, a mathematics model also has been built which based on Homogeneous model. It considered the two-phase mixture as a single fluid possessing mean fluid properties. The model is based on the following assumptions: the liquid phase and vapor phase have the same velocity, thermodynamic equilibrium between phases and use the single-phase friction factor to the two phase flow.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-MOPB105

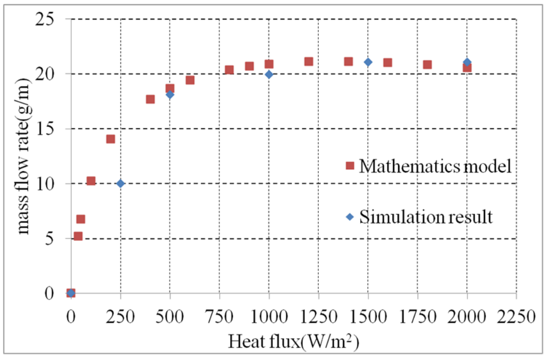


Figure 7: The 'U' shape model simulation results.

The simulation results and mathematics model show good consistency in Fig. 7.

The thermalsiphon loops in ICM has been simulated with similar mesh method and simulation settings in ANSYS-Fluent. The hexahedral mesh with 5 layers insulation on the tube wall and Multiphase-Mixture method have been applied to the model. Based on the simulation results the Max. Mass flow rate is about 3gm/s as shown in Fig. 8.

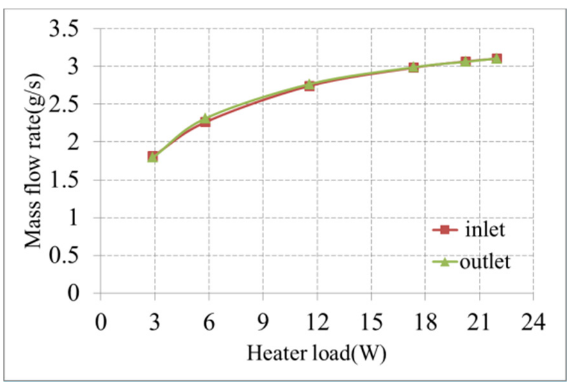


Figure 8: ICM Ansys-fluent simulation results.

THERMOSIPHON TEST RESULTS

The cavity design considers the use of two CPI couplers per cavity delivering a total of 100 kW of beam loaded RF power. The cold sections of couplers are cooled by LN loops, 80 K thermal links and 4 K siphon loops which will intercept the RF dynamic load in the 4K Helium instead of 2 K Helium. During the beam commissioning about 10 kW RF power is delivered through the couplers in standing wave mode as the beam loading is very weak. The temperature sensors related to the coupler siphon loops are which indicates the siphon loops work well.

With about 10 kW RF power, the temperature sensors related to the coupler siphon loops are about 17 K as shown in Fig. 9.

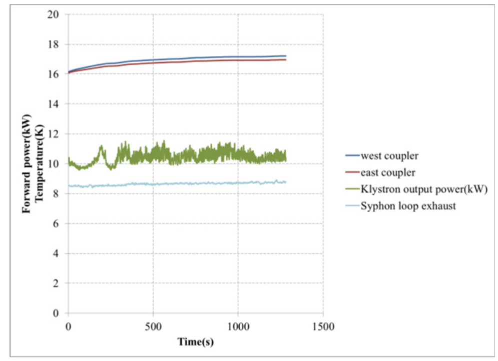


Figure 9: ICM FPC 4 K siphon loops related temperature.

The RF dynamic load to 4 K Helium through FPCs siphon loops has been measured by 4 K Helium falling level test by closing the 4 K supply valve and JT valve and keeping the RF on. The temperature sensors related to the coupler siphon loops indicated that the siphon loops work well. There is ~0.32W and ~1.2W RF load to the 4K reservoir for a total forward power for 2 couplers of 5kW and 10kW respectively.

DISSCUSION

A thermosiphon cooling scheme has been installed and tested in ARIEL Cryomodules for cavities cooling. The further optimization for the thermosiphon loops will be continued with the ARIEL commissioning progress.

REFERENCES

[1] R.E. Laxdal *et al.*, “The injector cryomodule for the ARIEL e-linac at TRIUMF”, in *Proc. LINAC2012*, Tel-Aviv, Israel, paper MOPB091, pp. 389–391.

[2] R.E. Laxdal *et al.*, “Cryogenic test of the 4 K/2 K insert for the ARIEL e-linac cryomodule”, *AIP Conf. Proc.*, vol. 1573, pp 1184-1191, 2014.

[3] S.R. Koscielniak *et al.*, “Electron Linac photo-fission driver for the Rare Isotope Program at TRIUMF”, in *Proc. IPAC2012*, New Orleans, Louisiana, USA, May 2012, paper MOOBC01, pp.64-66.

[4] M. Marchetto *et al.*, “Commissioning and operation of the ARIEL electron LINAC at TRIUMF”, in *Proc. IPAC2015*, Richmond, VA, USA, paper WEYC3, pp. 2444–2449.

[5] S. Koscielniak *et al.*, “TRIUMF ARIEL e-Linac Ready for 30 MeV”, in *Proc. IPAC2017*, Copenhagen, Denmark, May. 2017, paper TUPAB022, pp 1361-1364.

[6] R.E. Laxdal *et al.*, “The 30MeV stage of the ARIEL e-Linac”, presented at SRF2017, Lanzhou, China, paper MOXA03, this conference.

[7] N. Muller, *et al.*, “TRIUMF’s injector and accelerator cryomodules”, in *Proc. SRF2015*, Whistler, BC, Canada, Sep 2017, paper THPB115, pp.1409-1412.

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2017). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.