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RECONDENSING REFRIGERATOR FOR SUPERCONDUCTING NMR-CT

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This paper mainly describes a compact closed-cycle helium refrigerator (3.5W at 4.3K) and a recondensing system using the refrigerator of the evaporated helium gas of superconducting NMR-CT at Medical Center of Chiba University in Japan. The cycle of this refrigerator consists of a two-stage Sumitomo's modified Gifford-McMahon cycle refrigerator and a Joule-Thomson loop. For the recondensing system, direct-mounted-type refrigerator unit has been selected. After removal of magnet current lead from S.C.M. cryostat of the NMR-CT, the recondenser connected to the end of transfer tube of the refrigerator unit is inserted through the magnet current lead entry. The refrigerator provides its helium mist coolant to the recondenser located in the gas phase of the liquid helium vessel of the S.C.M. cryostat and refrigerator's helium mist coolant in the recondenser suppreses gas phase pressure inside the liquid helium vessel. It indicates recondensation of evaporated helium gas inside the liquid helium vessel.

Now we have been successfully accumulating running data of this recondensing system and no electromagnetic brake against the refrigerator operation from the S.C.M. cryostat has been observed and also no NMR image distortion has been caused by the refrigerator operating near the S.C.M. cryostat.

Key words: Compact heat exchanger; cryogenic refrigerator; helium recondenser; NMR-CT; superconducting magnet

1. Introduction

Nuclear magnetic resonance (NMR) has now become an exceptionally powerful investigative technique in the life science and the material science. In the field of medicine, NMR-CT is used especially for imaging of humans to examine medical diagnosis.

All NMR use magnets, while a few instruments use permanent magnets and electromagnets, most instruments use superconducting magnets because the large bore high field, high homogeneity, and high stability are required to the magnets. It promises to provide the first large scale commercial market for cryogenic component because as the key component of S.C.M. NMR-CT, the superconducting magnet is essentially needed. To maintain the superconducting magnet in NMR-CT at liquid helium temperature, liquid helium of 0.4 l/h and liquid nitrogen of 1.0 l/h are usually consumed (1)[1], so such cryogen transfer is needed at regular intervals.

We have developed a recondensing refrigerator system of the evaporated helium gas of the S.C.M. NMR-CT. Without liquid helium refill, the system has made it possible to operate S.C.M. NMR-CT continuously. This paper mainly describes the results of the performance of the recondensing refrigerator system.

2. Recondensing system

There are some practical cryogenic refrigeration system for S.C.M. NMR-CT. The S.C.M. cryostat in which the radiation shields are cooled by axillary refrigertors such as two stage G-M refrigerator, can do away with the need for liquid nitrogen and can reduce liquid helium consumption to less than half but not to zero.

Our purpose is to provide a refrigeration system to need not refill liquid helium by recondensing the evaporating helium gas within the cryostat.

3. Layout of system design

Layout of the refrigeration system for the S.C.M. NMR-CT is shown in fig. 1. The refrigeration system consists of refrigerator unit, compressor unit and gas helium line.

The refrigerator unit has the transfer tube and the recondenser is connected to the end of transfer tube. Also, this refrigerator unit is suspended from the ceiling with the lift and can be moved up and down using the lift.

The compressor unit is installed in adjacent room and combined to the refrigerator unit with the interconnecting gas helium line. The refrigerator unit on the lift is moved to just above the S.C.M. cryostat. And after removal of magnet current lead, this refrigerator unit is precisely moved down with the lift. The recondenser is inserted through the magnet current lead entry and located in the gas phase of the liquid helium vessel of the S.C.M. cryostat.

[1]Numbers in brackets refer to the literature references listed at the end of this report.

4. Compact helium refrigerator

Flow diagram of compact helium refrigerator for the S.C.M. NMR-CT is shown in fig. 2. The refrigerator unit is the combination of a two stage Sumitomo's Gifford-McMahon cycle refrigerator and a Joule-Thomson loop. This Sumitomo's Gifford-McMahon refrigerator is the modification of so called Gifford-McMahon refrigerator. Sumitomo's Gifford-McMahon refrigerator (SRD-208) have been widely used as a cryopump refrigerator.

The Sumitomo's SRD-208 has a hybrid mechanism of displacer by simultaneous use of drive motor and highpressure helium gas, and meets such a requirement of a small, compact, noiseless and reliable refrigerator.

The Joule-Thomson loop itself consists of three heat exchangers and Joule-Thomson valve. The heat exchangers are laminated metal-plastics heat exchangers (2) of light weight and high efficiency, developed for the on-board refrigerators in Japanese National Railways Superconducting Magnetic Levitated Train Project.

The recondenser is a vertical condenser type where condensation takes place on the outer surface. To enhance condensation heat transfer surface, a vertical shallow-fluted tube is used.

The compressor unit is constructed with two hermetic type compressors, oil separator, adsorber, storage tank, and control safety devices.

Capacity of the refrigerator is 3.5W at 4.3K and electrical power is about 7.5KW. Noise level of refrigerator unit and compressor unit are about 51(dB) and 54(dB), respectively. A photograph of the refrigerator is shown in fig. 3.

5. Preliminary test

Preliminary tests conducted are as follows;

(a) Refrigerator reliability test
(b) Recondensing test
(c) Refrigerator operation test under magnetic field
(d) Influence of refrigerator to S.C.M. NMR-CT image

Test results are mentioned briefly.

(a) Refrigerator reliability test

We have already developed several prototype refrigerators of 3.5W at 4.3K refrigeration capacity and we have been running these refrigerators more than 15000 hours successfully ever since.

(b) Recondensing test

Fig. 4 shows the recondensing test apparatus. In this test, heat load is given by electric heater immersed into the liquid helium. Test results are shown in fig. 5 and fig. 6. Fig. 5 shows the relation between equilibrium pressure versus heater input. In this test, the distance between recondenser and liquid helium level is kept constant, 100mm, and only J-T flow is changed as a parameter.

Fig. 6 shows test results at constant J-T flow rate. Parameter is only distance of recondenser and liquid helium level. The higher the distance is, the higher equilibrium pressure of the vessel is observed. This means slight liquid helium temperature rise in this vessel.

(c) Refrigerator operation test under magnetic field

By assuming that only motor of the refrigerator will be affected by magnetic field, we have tested magnetic effect to the refrigerator, and it is confirmed it can be operated until 1000 gauss.

(d) Influence of refrigerator to NMR-CT image

We have measured phantom image distortion according to the change of location of the refrigerator. The results are as follows;

When this refrigerator is located at 30 gauss line, no image distortion is observed. But at 100 gauss line, a slight distortion is observed, so at 100 gauss line location, shimming procedure of S.C.M. cryostat is to be needed.

6. Installation and performance

We installed the compact helium refrigerator to the S.C.M. NMR-CT at Medical Center of Chiba University in March, 1986. Fig. 7 is a photograph of the recondensing system of the S.C.M. NMR-CT at Chiba University. The relation of the liquid helium level and the pressure of liquid helium vessel and the running time is shown in fig. 8. After this initial running, the gas helium vent line of the S.C.M. cryostat was closed. the pressure of the vessel began to rise. After a few days, we have controlled the J-T valve in order to adjust operation condition. Finally we have established stable operating condition. However long large slow variation of equilibrium pressure (0.110-0.114MPa) will be observed. We think this variation will be caused by several conditions, such as environmental and other unknown conditions. Also fig. 8 shows that the liquid helium level was almost kept constant, that means helium loss became zero.

7. Conclusions

The recondensing system of evaporated helium gas has made it possible to operate the S.C.M. NMR-CT without the liquid helium refill. The electromagnetic effect of the magnetic fields of S.C.M. cryostat to the refrigerator operation has not been observed and also NMR-image distortion to be induced by refrigerator operation has not been observed owing to shimming procedure. During operation, there were no indications of contaminant freeze out in this refrigerator system. This successful operation data and performance of the recondensing refrigerator has been confirmed its versatile adaptability to S.C.M. NMR-CT system.

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8. References

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(2) Koizumi, T., et al., A small and light weight heat exchanger for on-board helium refrigerator, NASA Conference Publication 2287, 179-188 (1983).

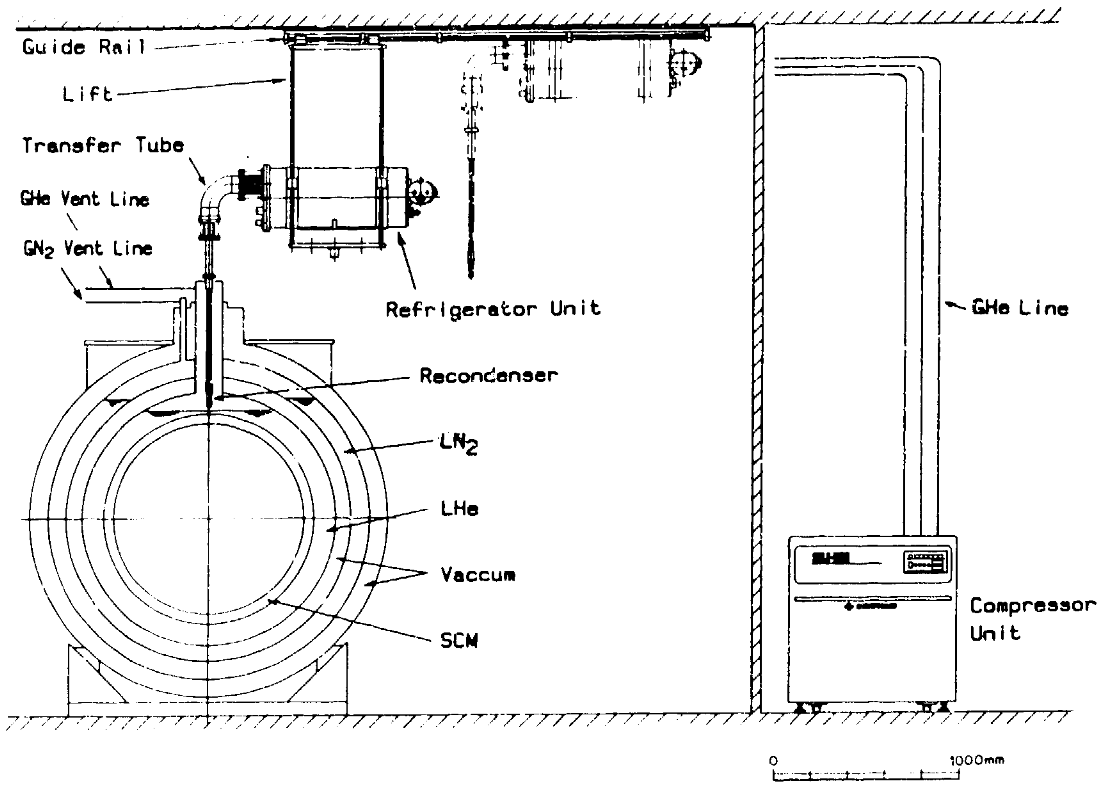

Fig. 1 Layout of compact helium refrigerator for superconducting NMR-CT

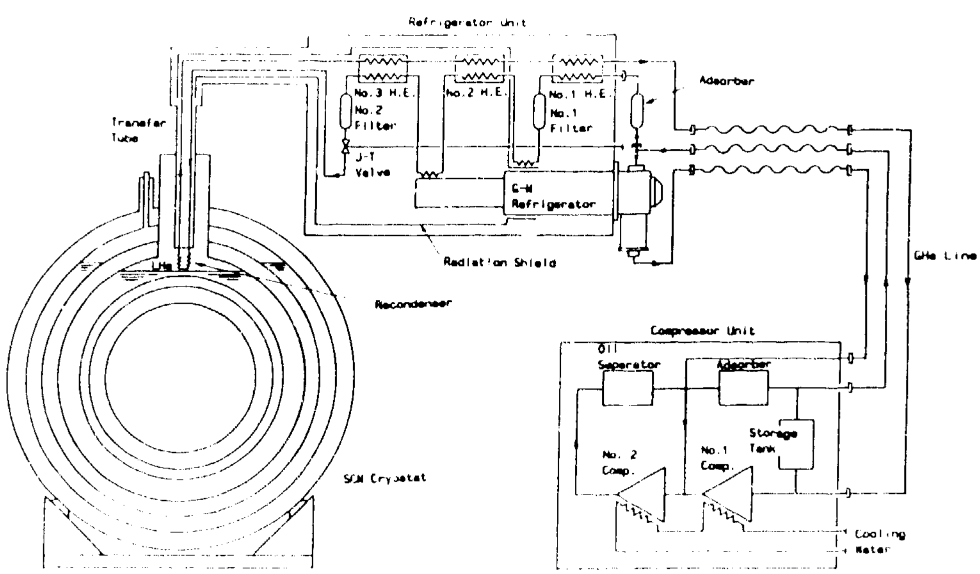

Fig. 2 Flow diagram of compact helium refrigerator for superconducting NMR-CT

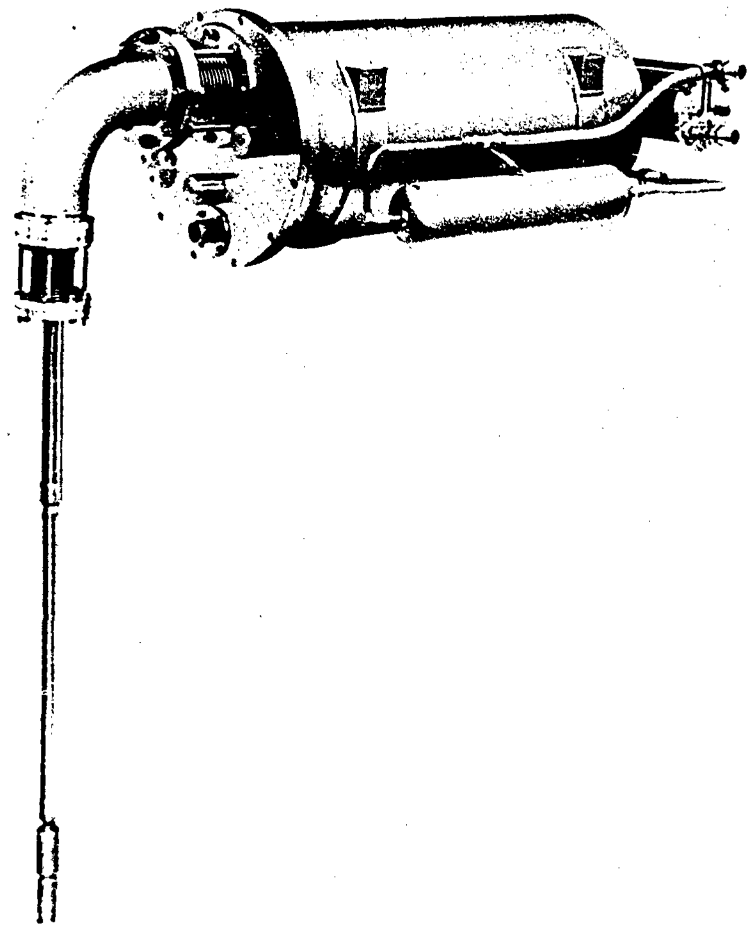

Fig. 3 The recondensing refrigerator

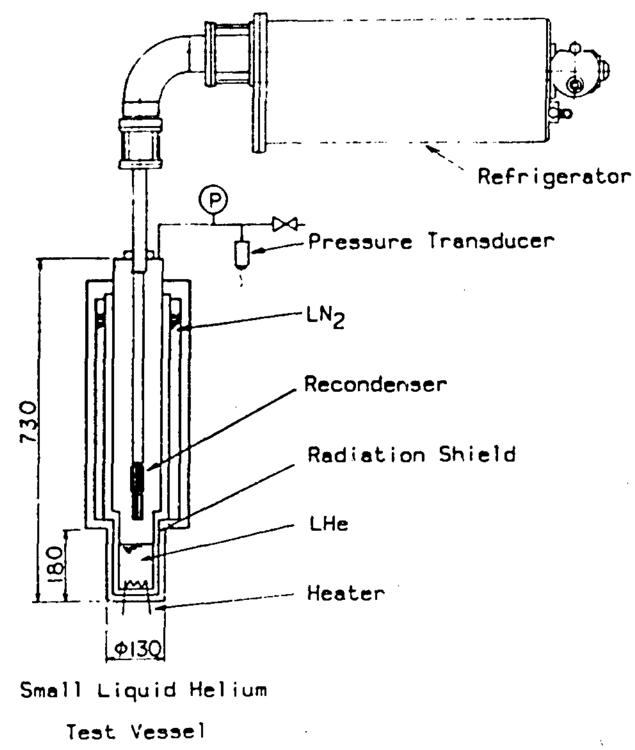

Fig. 4 Apparatus of recondensig test

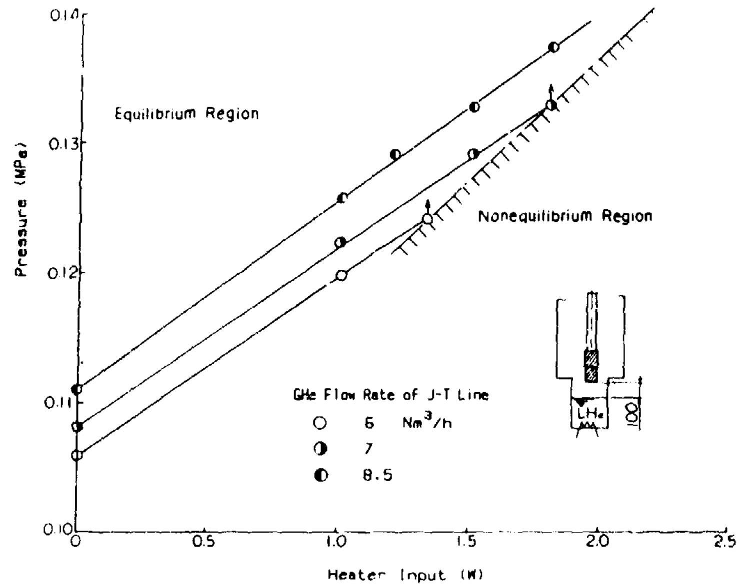

Fig. 5 Pressure versus heater input (1)

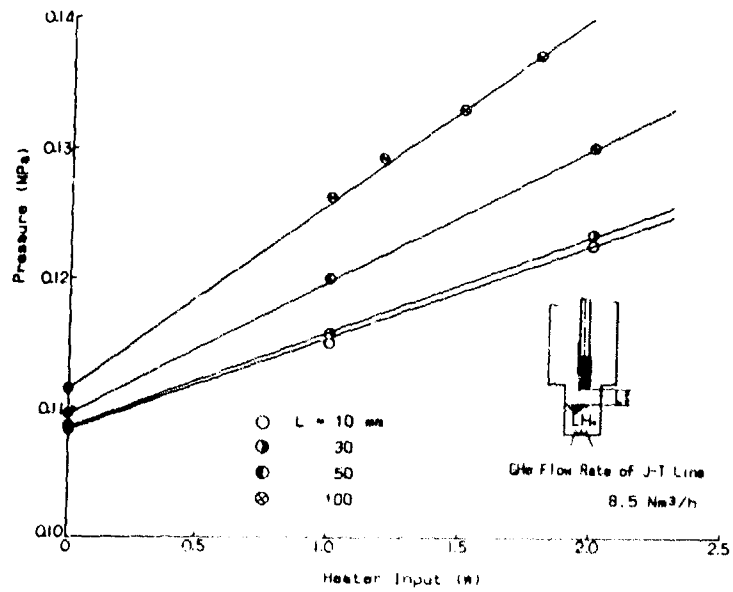

Fig. 6 Pressure versus heater input (2)

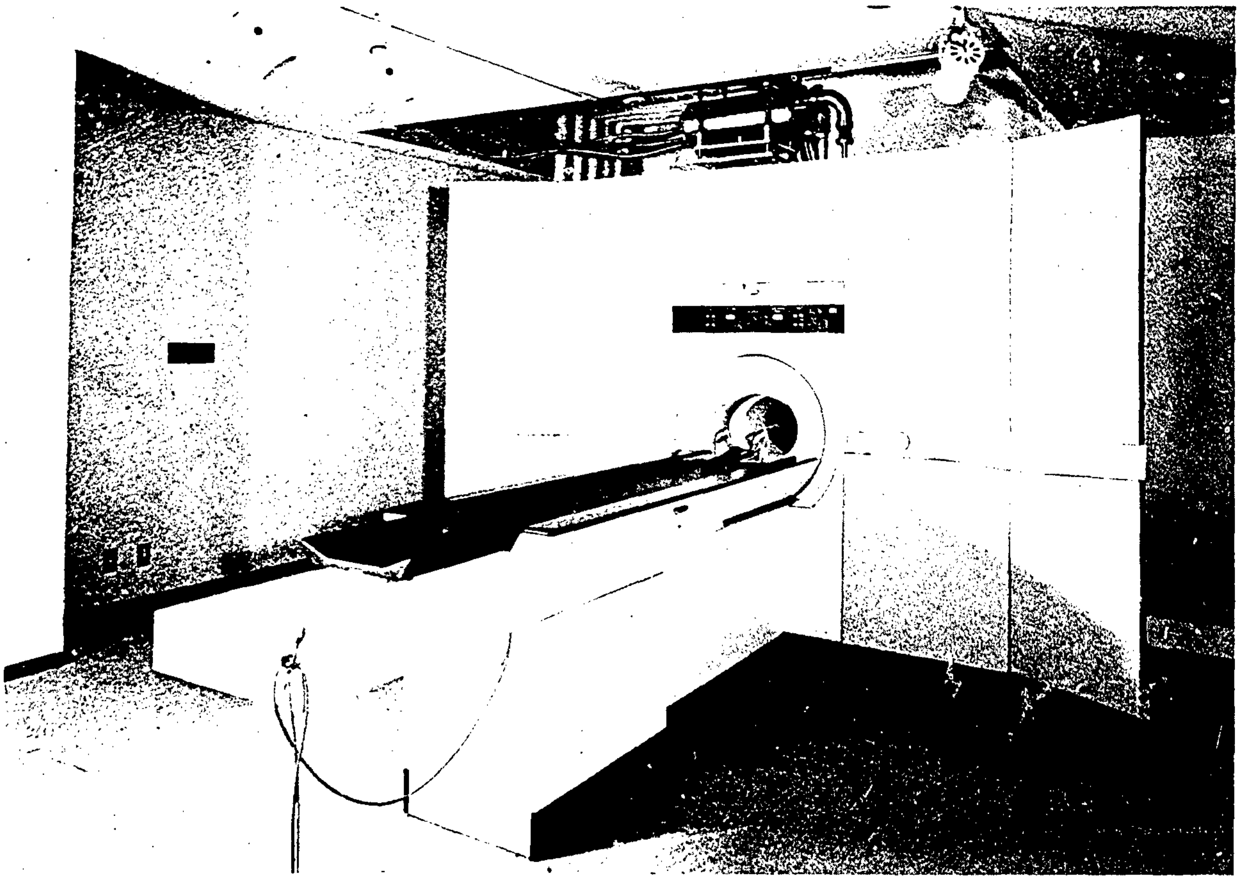

Fig. 7 The recondensing refrigerator system of the S.C.M. NMR-CT

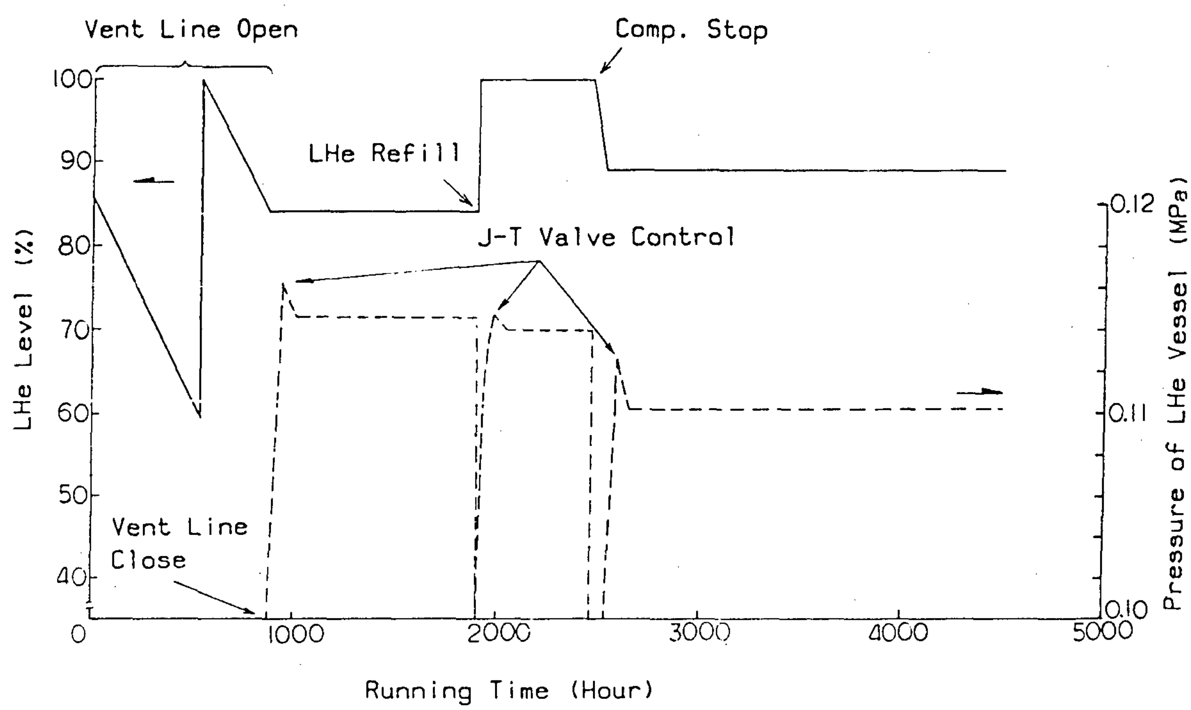

Fig. 8 Performances of compact helium refrigerator installed superconducting NMR-CT