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MAGNETICALLY LEVITATED VEHICLES BY SUPERCONDUCTING MAGNETS

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Abstract

Magnetically levitated vehicles propelled by a linear motor (Maglev) using superconducting magnets are being developed for a future high speed ground transportation. In this report, the Maglev system is introduced especially on the superconducting magnets and the on-board cryogenic systems.

KEY WORDS: (High speed transportation)(Superconducting magnet)(Liquid Helium)(Refrigerator)(Cryostat)

1. Introduction

The most important requirements for the future high speed ground transportations, are safety, comfortability and minimum public nuisance.

Safety and comfortabitlity of a vehicle mainly depend on its suspension systems and the flatness of the guideway. But the guideway cannot in reality be completely flat.

The faster the speed of the vehicle, the lower the ride quality becomes for reason of the gauideway's irregularity.

One of the best solutions for this problem is to levitate the vehicle without any contact to the guideway.

Two kinds of techniques are now being developed to levitate the vehicle magnetically. One is the electro-dynamic suspension (EDS) system and the other is the electro-magnetic suspension (EMS) system. EDS uses magnetic repulsive forces and EMS uses magnetic attractive forces.

The Japanese National Railways (now JR group) has been developing the EDS type of vehicle using superconducting magnets. This vehicle is called Maglev.

The principal features of a repulsive magnetically levitated vehicle using superconducting magnets, are that the vehicle can levitate as high as 10 cm above the guideway. This is the most suitable system for high speed ground transportation with high level of safety.

This vehicle is levitated, guided and also propelled by linear motors which also work magnetically. So it runs without any contact to the ground facilities, causing no contacting noise unlike usual vehicles.

2. The test vehicles

Table 1 shows the main history of the development of the Maglev system. A 7km length test track for high speed running was constructed in Miyazaki prefecture in 1977.

The first test vehicle ML500 (Fig.1) attained a world test record speed of 517 km/h in December 1979.

Since 1980 a second test vehicle MLU001 (Fig.2) has been operated to collect the data on ride quality and the dynamic characteristics of a 3-car train. In March 1987, this test vehicle achieved a manned running records of 401 km/h. And it was proved that this vehicle could run safely over artificially missaligned guideway as high as 30 mm afloat from the perfect level condition.

A new type vehicle MLU002 was constructed in May 1987 succeeding to MLU001. Fig.3 shows MLU002 running on the test guideway, and Table 2 shows the main parameters of MLU002. The dimensions of this vehicle are 22 m length, 3 m width and 3.7 m height. The total weight of the vehicle is 17 tons, which is very light compared to the ordinary rail vehicle. Fig.4 shows the details of MLU002. As shown in Fig.4, enough space for 44 seats is provided in this vehicle.

MLU002 has two bogies, each mounted with 6 superconducting coils. Every coil serves for levitation, guidance and propulsion of the vehicle.

Up to January 1988, the total running distance has accumulated to about 4000 km, the maximum speed being 354 km/h. In the planning of high speed running, the most important problem is not how to improve the acceleration performance of the vehicle but how to stop safely within only 7 km length of the test guideway.

Table 1 Main history of Maglev development

Early 1960s	Research for linear motor propulsion and non-contact run started
1970	Basic test facilities for superconductive maglev completed
1972	LSM propulsion experimental vehicle (LSM200) succeeds in levitated run LIM propulsion experimental vehicle (ML-100) succeeds in levitated run High-speed characteristic of cycloconverter (500 km/h eguipment) tested
1975	LSM-propulsion experimental vehicle (ML-100A) succeeds in perfect non-contac trun
1977 April July	Miyazaki Maglev Test Center opened Running test of ML-500 on inverted-T guideway starts at Miyazaki Test Track
1978 Nov	347km/h run attained (with magnetic Levitatim)
1979 Jan. May Dec.	Simulated tunnel run tested Run with helium refrigerator onboard tested 517km/h run attained (with magnetic levitation)
1980 Nov.	Running test of MLU001 on U-type guideway starts ar Miyazaki Test Track
1982 Sept.	Manned test of MLU001 on U-type guideway starts at Miyazaki Test Track
1983 Aug. Des.	400km/h run of a singie vehicle attained 352km/h run of three vehicles coupled attained
1987 Feb. Apyil May	400.8km/h run of two vehicles coupled (manned) attained Railway Technical Research Lnstitute reorganized as a research foundation, taking over the R & D work so far pursued Test run of MLU002 starts

Fig.1 Test vehicle ML500

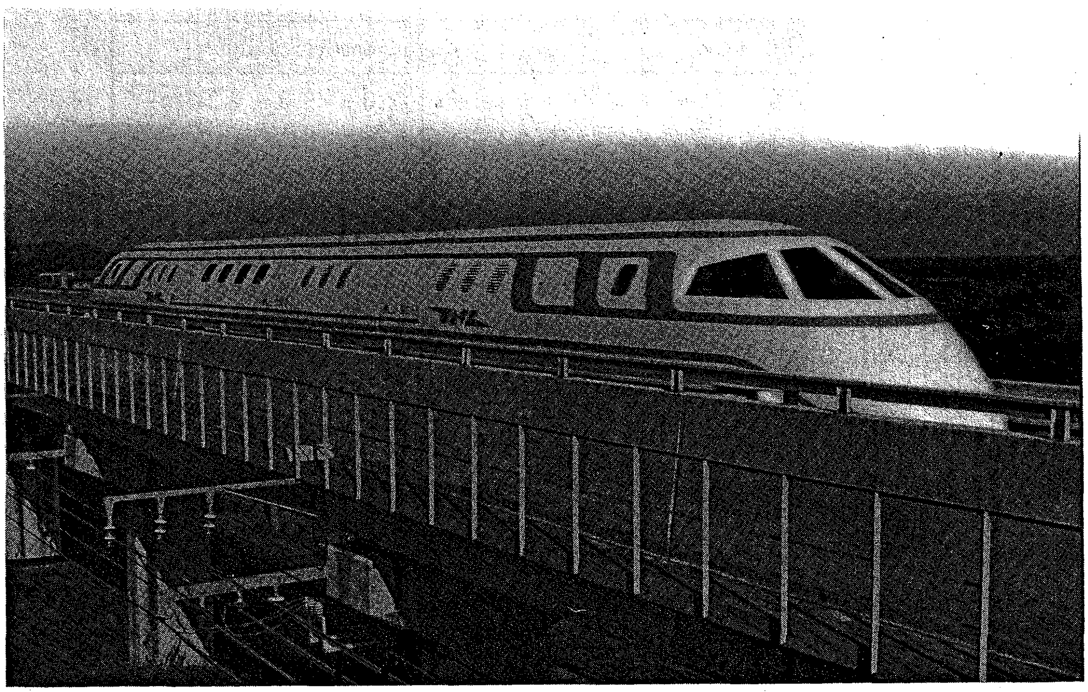

Fig.2 Test vehicle MLU001

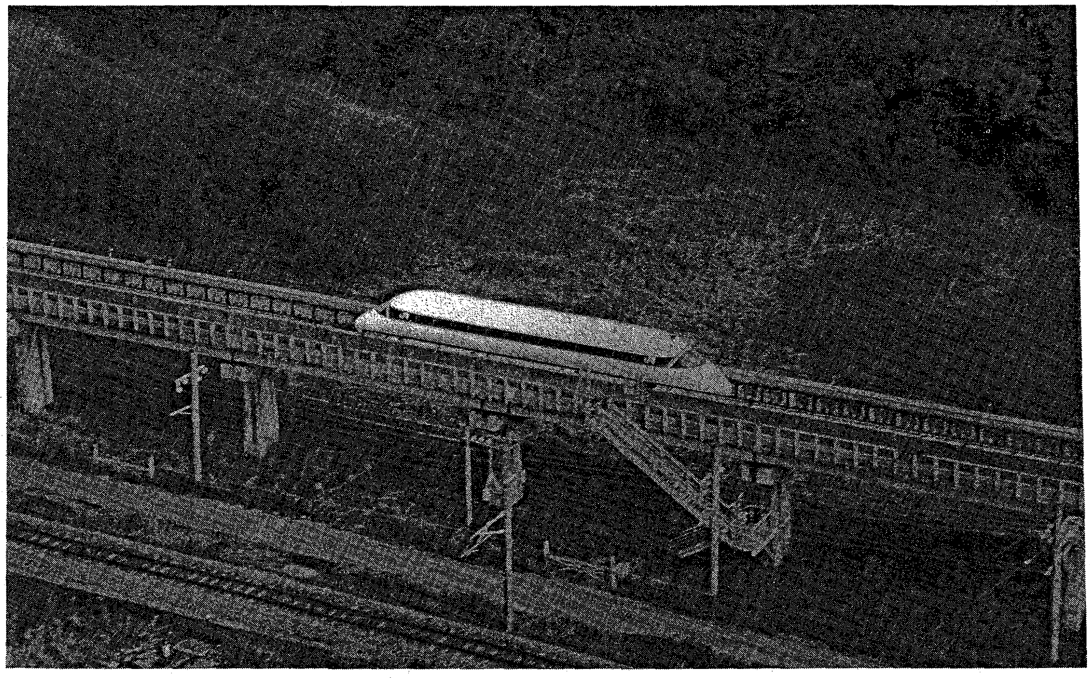

Fig.3 Test vehicle MLU002

Table 2 Main parameters of MLU002

Ltem		Specification
Vehicle dimensions	Length x width x height Mass Seating capacity	22.0 m×3.0 m ×3.7 m 17t 44
Superoonducting coil	Number of coils Magnetomotive force Pole pitch	6 poles ×2 rows 700 kA 2.1 m
Suspension	Lift Effective gap	196 kN 110 mm
Guidance	Guidance force Effective gap	83.3 kN at 50 mm shift more than 150 mm
Propulsion	Thrust Phase Frequency Voltage Current	0-79.4 kN 3 0-28 Hz 5800 V 900 A
Maximum speed		420 Km/h

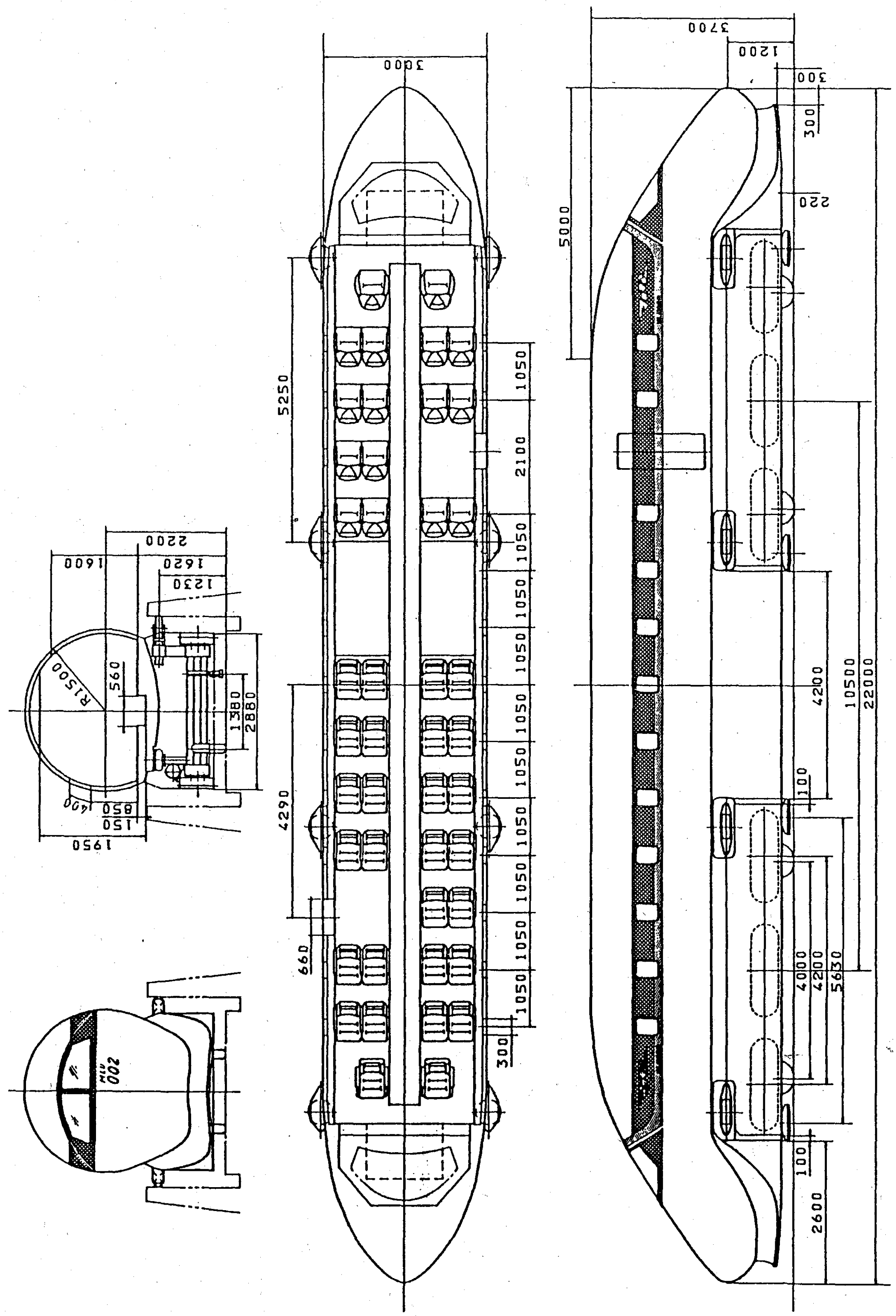

Fig.4 Details of MLU002

3. Superconducting magnets

Superconducting magnets consist of the superconducting coils and the cryogenic vessels, which are called cryostat. The details of the magnets are given in Table 3. The superconductive material NbTi is used, as fine-multi twisted wires. The superconducting wires are wounded in 1167 turns, like a race track shape. These coils are excited by about 650 A current, with a magnetomotive force of 700 kA. Each coil has a persistent current switch, at the both ends of the windings. So, once the coils are excited, the current continues flowing inside the superconducting wire, keeping strong magnets even after the current leads are taken off.

Fig.5 shows an outside view of the superconducting magnets. Each of the superconducting magnet units consist of four parts, i.e. three coils and one liquid Helium (LHe) tank unit. Each coil unit is connected to the LHe tank by a flange coupling and each vacuum vessel is isolated from the others. Therefore, if a trouble occurs in the cryostat of an SC coil, the safety can be secured by this structure.

The superconducting coils are impregnated with epoxy resin in order to fix the superconducting wires to each other. Fig.6 shows the comparison between two cross sections of the superconducting coil, one of which shows the coil for ML500 and the other for MLU002. The coils for ML500 have cooling channels inside the coil section in order to keep good cooling characteristics of the superconducting wires. In the case of MLU002, the whole cross section is fastened by epoxy resin without any cooling channels inside. From this comparison it is very clear that the new type coil has a smaller cross sectional area and is easier for fabrication.

Each coil is installed in an inner vessel, which also serves as a LHe vessel. This inner vessel is surrounded by high vacuum in order to minimize the heat leak into the LHe temperature region through gas convection. The outer vessel of the magnet is a vacuum container.

Between the inner and the outer vessels, thermal radiation shield plates are set for the purpose of preventing the thermal radiation from invading the LHe temperature region. This radiation shield plate is cooled by liquid Nitrogen.

The superconducting coils are rigidly connected to the inner vessels, which are supported on thermally insulated supports. These supports have to stand the strong forces of levitation, propulsion and guidance which act electro-dynamically on the superconducting coil itself.

These insulated supports are made of fiber reinforced plastics (FRP), for reason of its low thermal conductivity and high mechanical strength. Some of the supports use the FRP made of carbon fibers, because the thermal conductivity drops at the cryogenic temperature unlike the most popular FRP made of the glass fibers.

Liquid Helium is supplied from the LHe tank, set upwards of the superconducting coils. The evaporated gas He comes up to the LHe tank, and is reliquefied by an on-board refrigerator. The on-board refrigerator is installed at one end of the LHe tank.

The total heat leak to the LHe temperature region is about 3 W for one set of superconducting magnets. The on-board refrigerator has about 5 W of refrigeration capacity at 4.3 K. So, it is possible to increase the volume of the LHe by this surplus refrigeration capacity if necessary.

4. On-board refrigeration system

From the beginning of the development of the refrigeration system for the Maglev vehicle, the principal concept is that a superconducting magnet is kept at cryogenic temperature without discharging Helium into the atmosphere by the

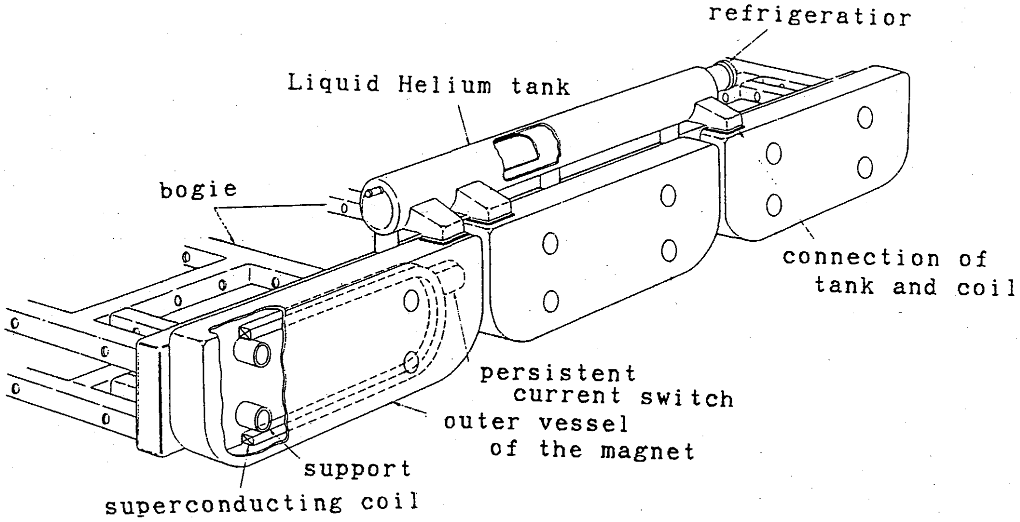

Fig.5 Superconducting coil for MLU002

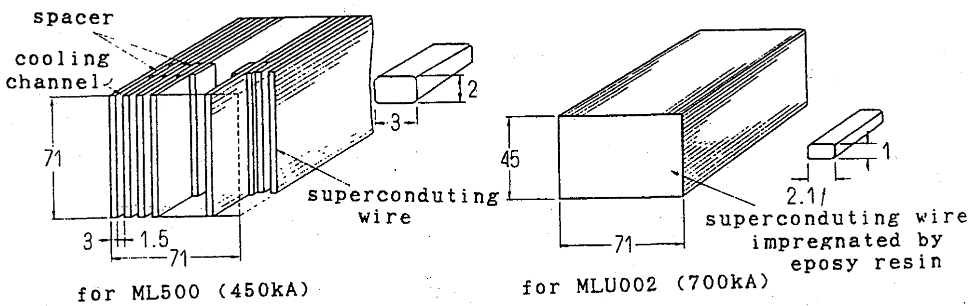

Fig.6 Comparison of the cross section of the superconducting coil

Table 3. Basic Specification of SCM used for MLU002

Item	Specification
Shape	I-shaped
Composition	1 coil/cryo × 3+ LHe Tank
Dimension of SCM	6.1 m^L × 0.885 m^H
Magnetomotive force	700 KA
Dimensions of SC coil	1.7 m^L ×0.5 m^W
Copper ratio of superconductor	1
Support	FRP column
Persistent current switch	
· off-state resistance	50
· switching speed	10 s
Heat leak to inner vessel	3 W
Weight	950 kg
ON-board refrigerator	
· refrigeration capacity	5 W at 4.3 K
· cycle	Clonle cycle & Stirling cycle

on-board refrigerator.

Fig.7 shows a schematic view of an example of the on-board refrigerator. This example shows a Claude cycle refrigerator; a Stirling cycle refrigerator has been also developed for the Maglev vehicle.

The important matter for the on-board refrigerator is that it must be designed as small and light as possible. In order to meet this target, expanders and heat exchangers of new types have been developed. Fig.8 shows the details of the laminated type heat exchanger, which is used in a Claude cycle refrigerator.

Recently the expander is incorporated into the heat exchanger in one body, making the volume smaller than before. This type of refrigerator is incorporated in the superconducting magnet shown in Fig.5.

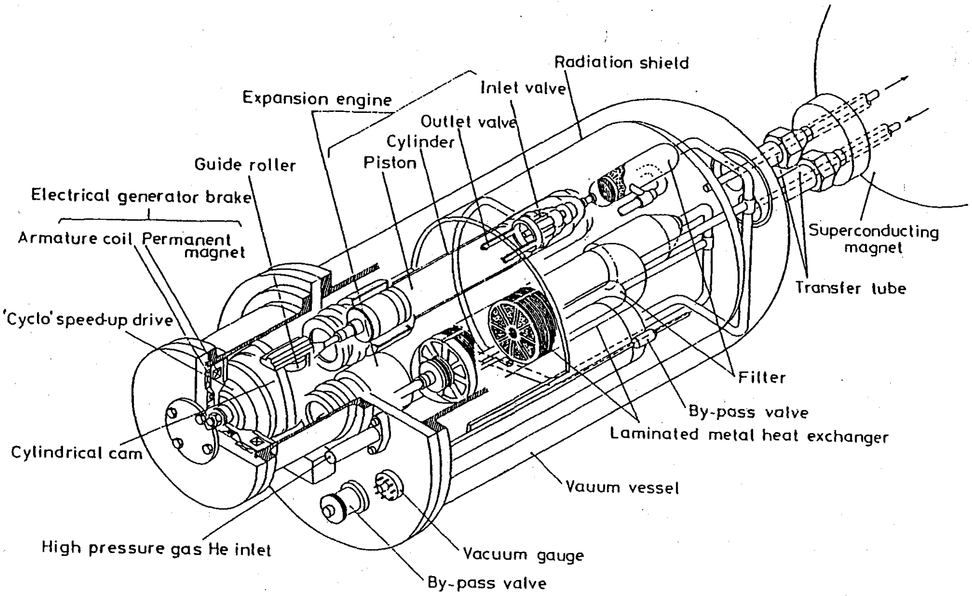

Fig.7 Schematic view of the on-board refrigerator

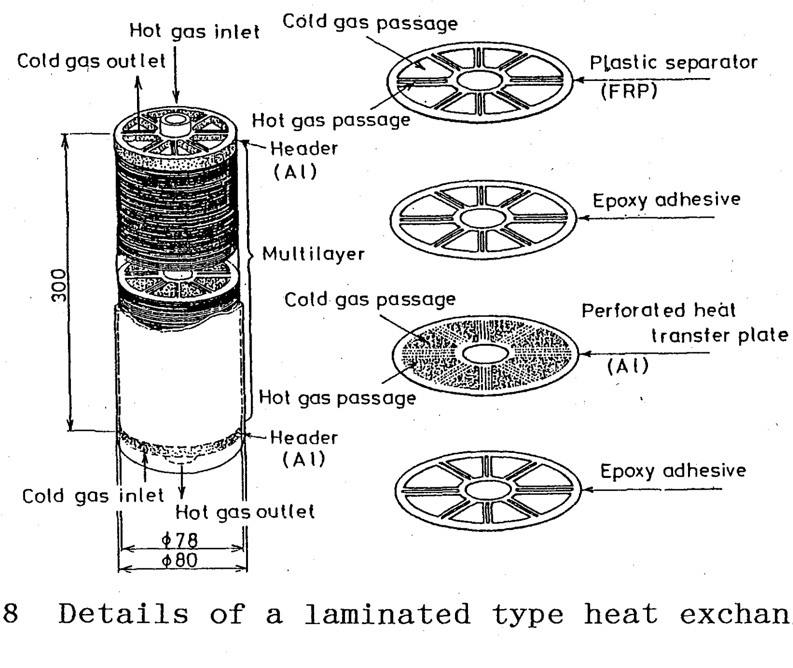

Fig.8 Details of a laminated type heat exchanger

5. Expectation for future technology

It any age, new developments depend on new materials, new machining or treatment technology and new ideas. This is also true with Maglev development. Maglev has been successful to many new basic technologies built up in other areas.

Still now there are many technological points which call for improvement. In closing this report, some of these points are disclosed.

a. Superconducting materials

Until only two years ago, high temperature superconducting materials remained one of the dreams of all people concerned in superconducting technology. As is well known it is not a dream now. If the new high temperature superconductive materials can be used for Maglev, the on-board refrigeration system will be far more simplified. At present, now, the maximum current density of this material is not high enough to make desired superconducting magnets.

Now it is the next dream to use these high temperature superconductive materials instead of NbTi wires.

b. Junctions between different materials.

Superconducting magnets must fulfill some special conditions imposed on each component. For instance, the materials of inner vessels should be strong enough at cryogenic temperature, and the stainless steel is mostly used. On the other hand, the materials of outer vessels must possess high electric conductivity, enough strength and small specific gravity. For the above reasons, a Aluminum is chosen for the materials of outer vessels in almost all cases. The junctions between two different metals have to be not only strong enough but also vacuum-tight enough.

Now for the purpose of connecting different materials, friction welded metal blocks are prepared, and the same kinds of metals are welded to each other. If this junction can be easily done by other methods, the structure of the superconducting magnets will be simpler.

Furthermore, junctions between metals and ceramics are also very useful for superconducting magnets. They must be strong and vacuum-tight enough at cryogenic temperature with high reliability.

c. Materials of high specific heat.

As an on-board refrigerator, a Stirling cycle refrigerator is an excellent candidate because of its simple structure. This refrigerator comprises an important part named regenerator, which serves as a heat sink in a wide range of temperatures.

For the materials of this regenerator, high specific heat is the most important requirement. Regretfully, the specific heat of almost all materials drops with a temperature decrease.

As one of the solutions to this problem, rare earth materials such as GdErRh are used, because of their special characteristic. If some materials having enough specific heat below 20 K are available, the performance of the Stirling cycle refrigerator will be much improved.

d. Other requirements on materials.

In the design of the superconducting magnets, some other special requirements are imposed on materials. Sometimes, it is very difficult to find the materials that can sufficiently meet these requirements. Here some of these requirements are stated.

--Materials with good electric conductivity and small thermal conductivity.
For current power leads to the superconducting coils.

--Materials with high stiffness and high electric conductivity.

For radiation shield plates and outer vessels.
--Materials with thermal conductivity depending on direction.
For heat exchangers of the cryogenic refrigerators.
--Materials with good elasticity at cryogenic temperature.
For valve seats of the refrigerator.
--Materials with low friction coefficient at cryogenic temperature.
For pistons or other parts of refrigerators.

6. Closing remarks.

Superconductivity is a very fantastic phenomenon, and future prospects of its utilization have suddenly opened with the discovery of new high-temperature superconductive materials. Now, Maglev is only one of the representative developments using superconductivity, and many other interesting big projects are being promoted.

We hope that the Maglev project serves not only as a future high speed transportation system but also as one of the incentives for promoting the superconducting technology.

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