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Review and update on MAGLEV

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Outline

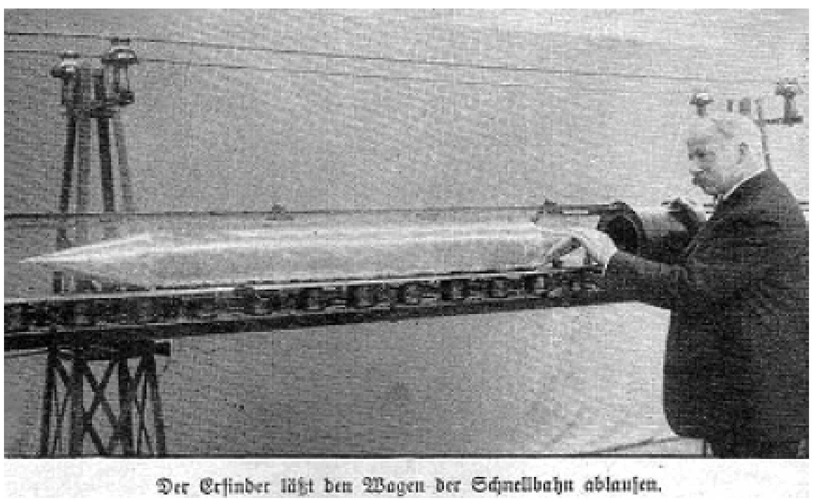
Review and update on MAGLEV

1. Introduction
2. Superconducting Magnet
3. History of Superconducting Maglev Development in Japan
4. Progresses of Superconducting Maglev Technologies
5. Chuo Shinkansen Plan
6. New Master Plan for Technology Development
7. Video of Superconducting Maglev and Yamanashi Test Line
8. Summary

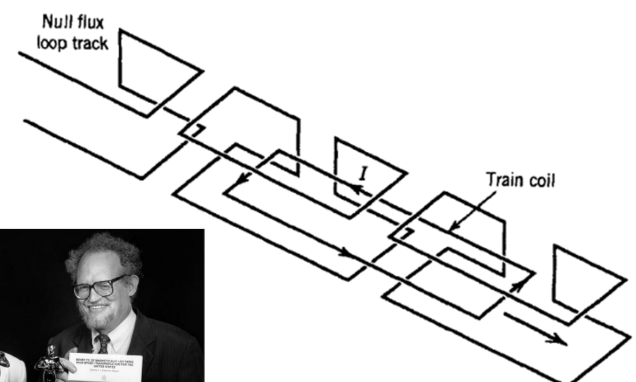
Invention of ElectroDynamic Suspension (EDS)

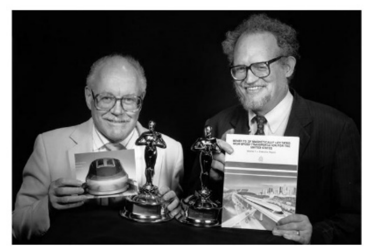
- In 1912 Emile Bachelet invented **magnetically levitating** transmitting apparatus and displayed a model. (EDS)
- In 1968 J. Powell and G. Danby proposed a new type of magnetic suspension, the null flux suspension.

Source: "Schwizer Familie" No. 35, June 27, 1914.



Emile Bachelet with his maglev model. He obtained an U.S. patent for levitating transmitting apparatus in 1912. <EDS>

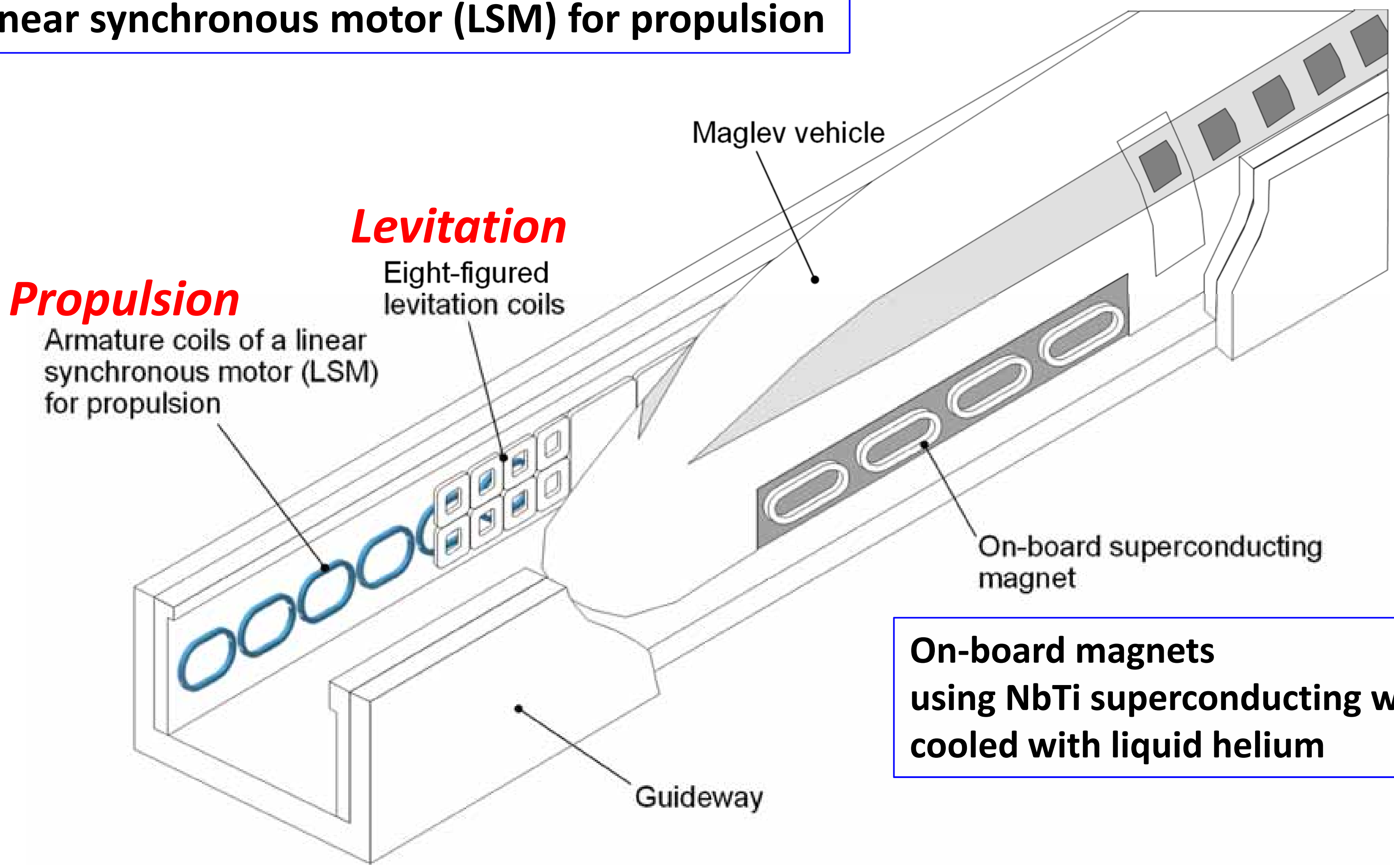




Null-flux coil guideway concept for EDS (Powell and Danby, 1968)

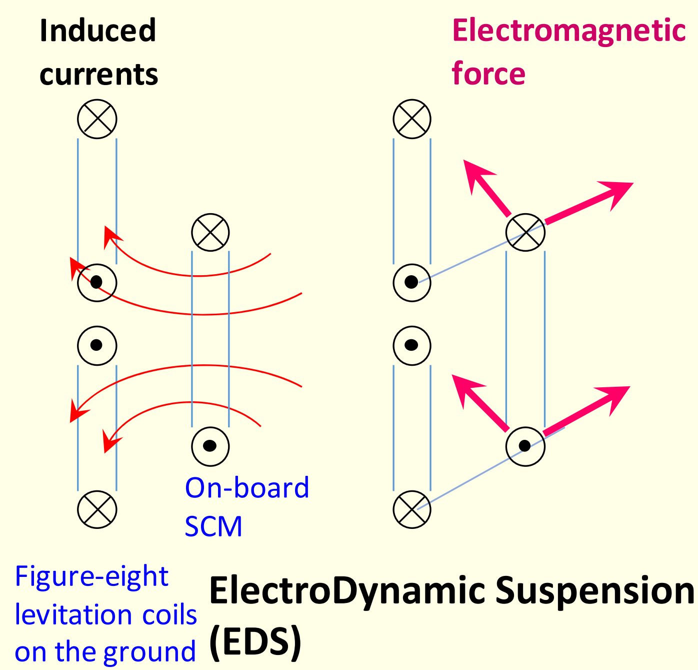
Superconducting Maglev System

Electrodynamic suspension (EDS) for levitation
Linear synchronous motor (LSM) for propulsion

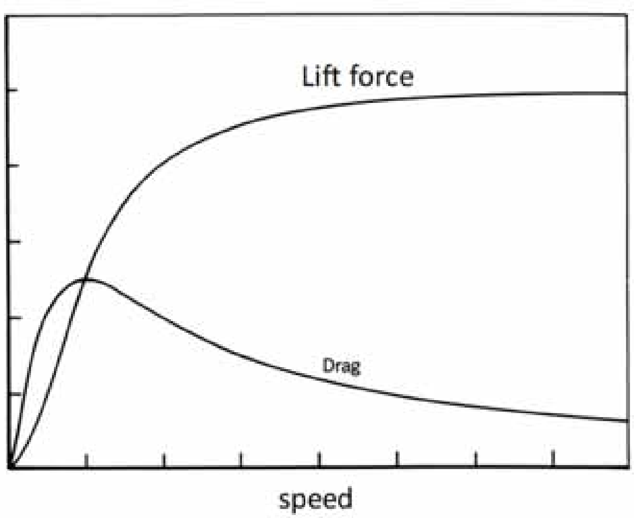


On-board magnets
using NbTi superconducting wire
cooled with liquid helium

Magnetic Levitation – ElectroDynamic Suspension

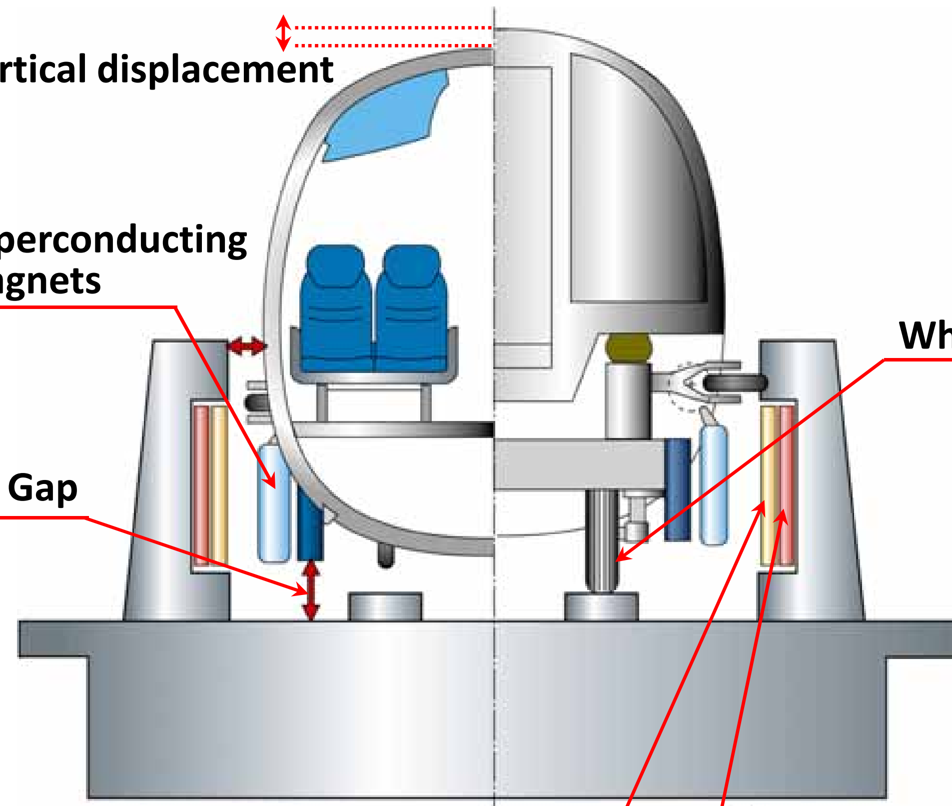


ElectroDynamic Suspension (EDS)



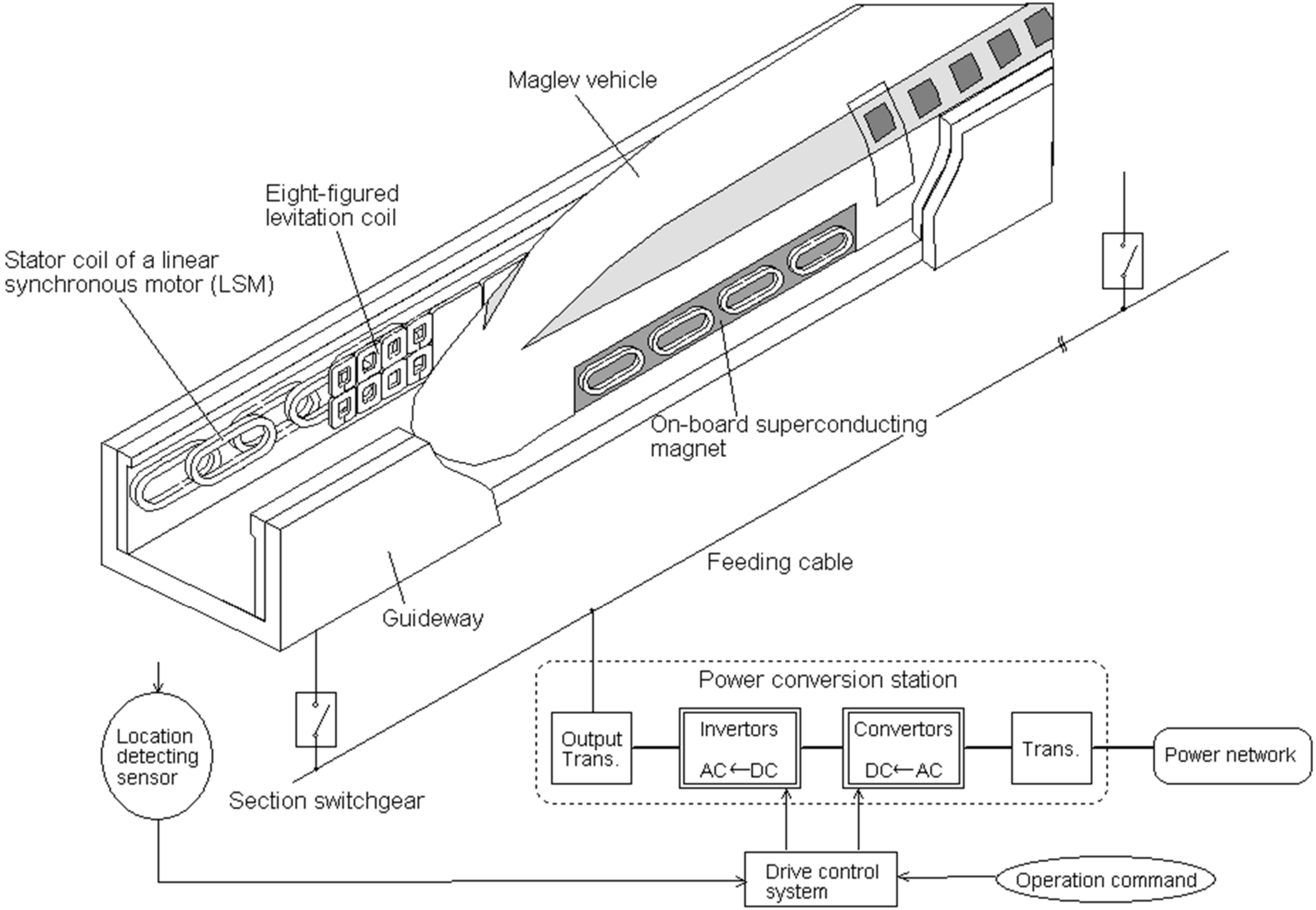
Magnetic levitation at high speeds

Travel with wheels at low speeds



Magnetic levitation
Speeds > 120～130 km/h
Gap about 10 cm
No gap control

Superconducting Maglev System



Yamanashi Maglev Test Line

- The superconducting maglev system has been tested on the Yamanashi maglev test line since 1997 aiming at its future practical application.
- It is located about one hour west from the center of Tokyo.
- In 1997, the constructed test line was 18.4 km, although the original plan was to construct 42.8 km long test line.
- The test line has a curve section of 8000 m radius and a 40 ‰ gradient, and meets the necessary conditions for the intended running tests of the system.

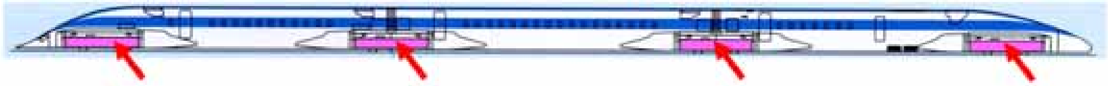
Superconducting Magnet

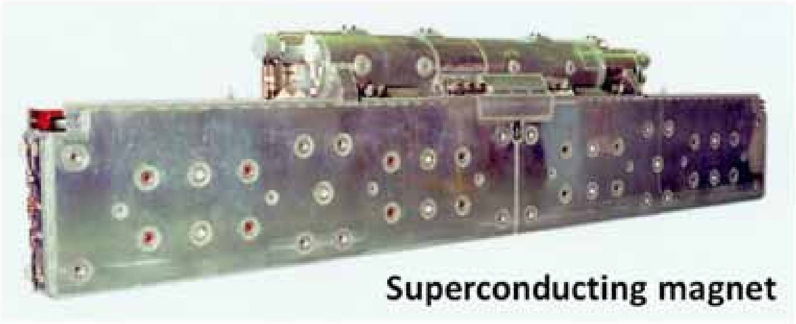
Fundamental structure of the on-board superconducting magnet

Racetrack-shaped NbTi superconducting coils generating four-pole magnetic field.
A 16-car maglev train will have 34 superconducting magnets and 136 superconducting coils in total

Key features

- ✓ Stable quench-free coil,
- ✓ Lower heat invasion,
- ✓ Reduced heat generation caused by electromagnetic and mechanical vibrations,
- ✓ Lightweight, etc.

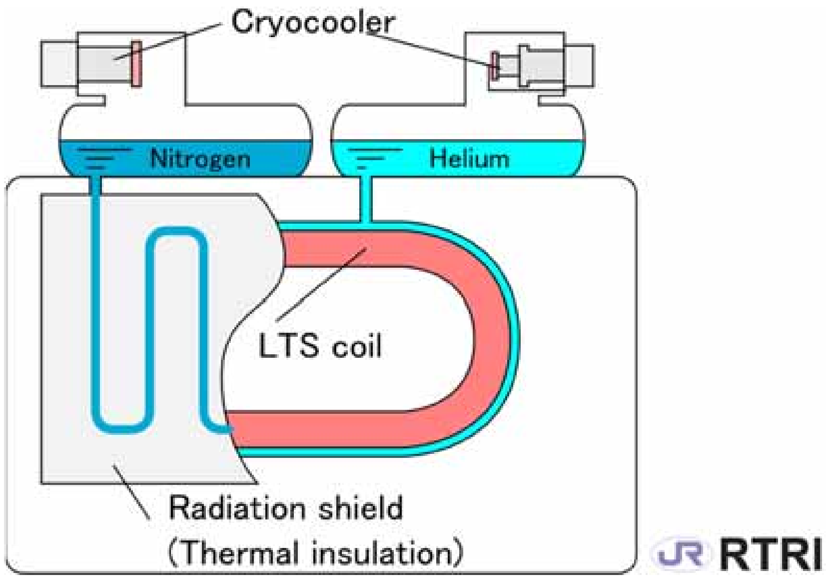




Superconducting Magnet

Superconducting magnet (SCM):

- NbTi superconducting wires
- Coolant: Liquid helium
- 4 K GM-JT cryocoolers for the closed-loop cooling system
- Radiation shields cooled by liquid nitrogen



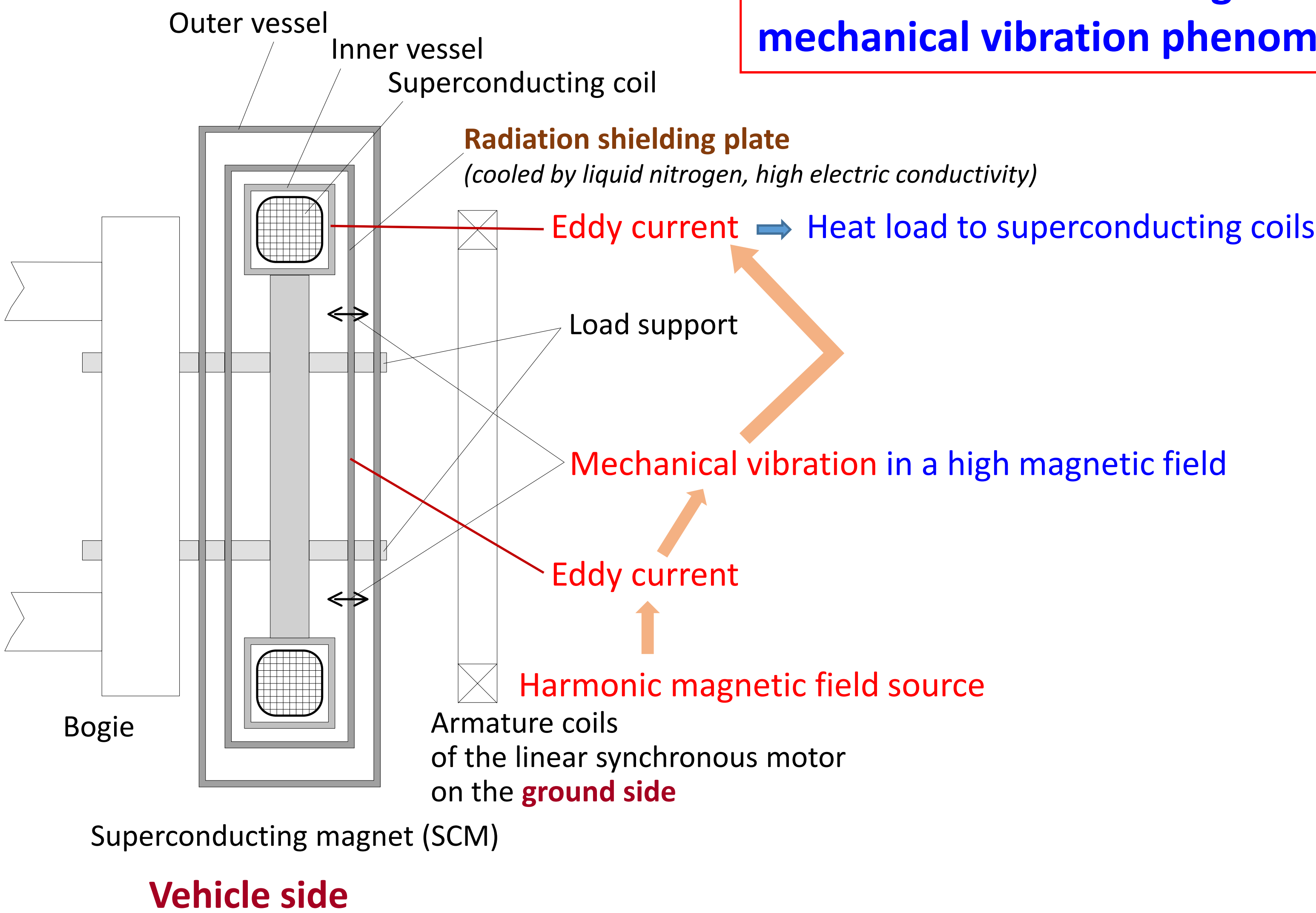
Example of magnet specifications

Size: 5.5 m long, 1.17 m high
Magnetomotive force: 700 kA
Pole pitch: 1.35 m
Superconducting wire: NbTi wire
Max. flux density: 5 T

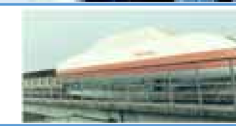
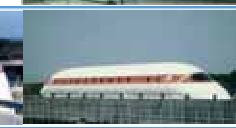
Thermal load (Standstill): < 5 W
Thermal load (Running): < 8 W
Cooling power: > 8 W

Electromagnetic Vibration of SCM

Resonance of electromagnetic and mechanical vibration phenomena



History of R&D of Superconducting Maglev in Japan (1)

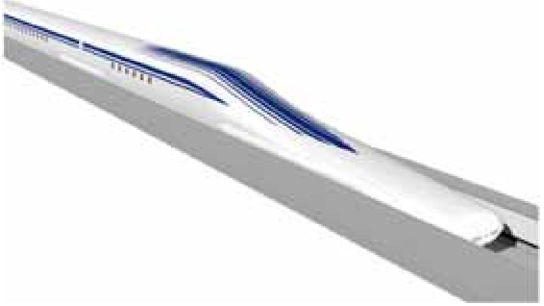
1962	Development of maglev started at JNR Railroad Technical Laboratory in Tokyo.
1970	Study of superconducting maglev started.
1972	First demonstration of superconducting magnetic levitation, LSM200, ML100 
1977	Miyazaki maglev test center opened, ML500 
1980	MLU001  
1987	MLU002
1990	Yamanashi Test Line plan approved. Construction started.
1993	MLU002N 
1997	**Yamanashi Test Line opened**, 531km/h (manned), 550km/h (unmanned) 
1999	552km/h (manned, 5-car), 1,003km/h (2 trains)
2003	581km/h (manned, 3-car)
2004	High speed passing test: 1,026km/h (2 trains)
2005	High-temperature superconducting (Bi2223) magnet tested (550 km/h).
2007	(in January) Extension of Yamanashi Test Line approved (from 18.4 km to 42.8 km)

History of R&D of Superconducting Maglev in Japan (2)

2007	JR Central announced in April 2007 that the commercial operation of the Chuo Shinkansen using superconducting maglev system between Tokyo and Nagoya would start in 2025.
	JR Central announced in December 2007 that the company would be responsible for all expenses necessary for the Chuo Shinkansen. Tokyo to Nagoya: about 290 km Start of revenue service in 2025 Construction and train costs: JPY 5.1 trillion Transportation capacity: 16-car maglev trains, 100 operations/track/day, 200,000 passengers/day
2009	In July 2009 the maglev technological practicality evaluation committee under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) acknowledged that “the technologies of the superconducting maglev have been established comprehensively and systematically, which makes it possible to draw up detailed specifications and technological standards for revenue service.”
2010	In April 2010, the JR Central pushed back the schedule for the start of operations of the Chuo Shinkansen from 2025 to 2027.
2011	In May 27, 2011 the MLIT minister designated the JR Central as the operator and constructor of the Chuo Shinkansen between Tokyo and Osaka.
	On-board power supply: Gas turbine generator to inductive power collection

History of R&D of Superconducting Maglev in Japan (3)

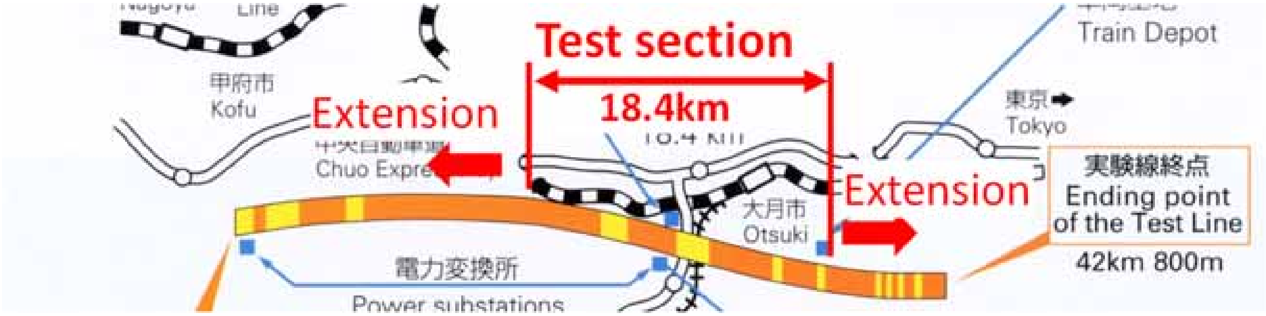
2011	(in September) Running test ended at the Yamanashi test line. The total running distance was about 874000 km. Test Track Extension and Facility Replacement.
2013	Extension of Yamanashi Test Line completed (42.8 km) Running tests restarted using the L0 type new vehicle.
2014	(in October) Approval of the construction implementation plan of the Chuo Shinkansen between Shinagawa and Nagoya. (in December) Construction of the Chuo Shinkansen started.
2015	(in April) 590 km/h on April 16 603 km/h on April 21 (World Speed Record) (in September) Full construction of Shinagawa Station in Tokyo started. About 40 m underground below the existing Tokaido Shinkansen Shinagawa Station.
2027	Commercial operation between Tokyo and Nagoya (290 km)
2045	Commercial operation between Tokyo and Osaka (67 min.)



The latest train type, the L0 series,
for commercial operation at 505 km/h

Extension of Yamanashi Maglev Test Line

- In September 2006, the JR Central announced that the company would renew the facilities of Yamanashi maglev test line and extend the line to **42.8 km** with its own fund of 355 billion yen.
- In September 2011 the running tests at the 18.4 km priority section ended.
- The total travel distance was about 874000 km for 14.5 years.
- The line extension was completed in the middle of 2013, and now the running test is being performed at the 42.8 km test line with the L0 type vehicles.
- A 12-car maglev train test operation are also carried out there.
- The Yamanashi maglev test line will be used as a part of the commercial line between Tokyo and Nagoya.



Important Technical Subjects

- High-temperature superconducting magnets
- Inductive power collection system for on-board power supply of the superconducting maglev system
- Millimeter wave radio system for detecting the train position
- Noise, ground vibration, tunnel micro-pressure wave, low-frequency noise, etc.
- Magnetic fields. But the magnetic field level can be low enough to fulfill the ICNIRP guidelines.

  (ICNIRP: International Commission on Non-Ionizing Radiation Protection)
- Vehicle fire prevention, earthquake safety, and fire safety in deep underground

Superconducting Magnet using Bi2223 wire

- **A superconducting magnet containing four Bi2223 superconducting coils (750 kA, 20 K) was fabricated, and the test of the vehicle carrying this Bi2223 magnet was carried out at Yamanashi Test Line from the end of November 2005 to the beginning of December 2005.**
- **Without any serious problems the speed of 550 km/h was achieved.**

Advantages of a high-temperature superconducting magnet (HTS magnet)

NbTi superconducting magnet (4 K)

Onboard refrigerator → More compact, liger weight; Reduced input power

Liquid helium tank -------------- → Removed

Liquid nitrogen tank -------------- → Removed

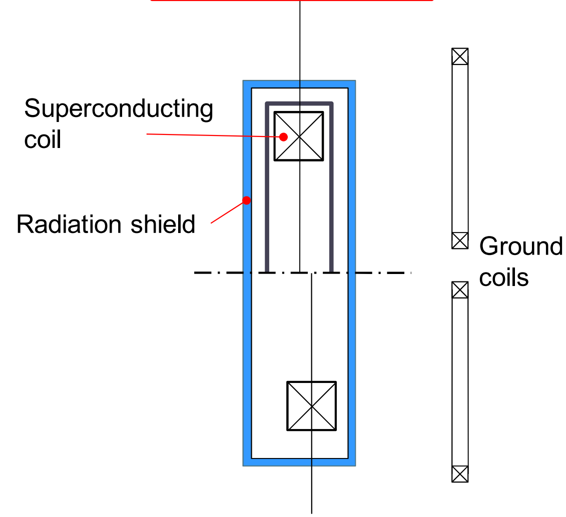
Outer vessel ----------- -------------- → Thinner

Radiation shield plate -------------- → Removed

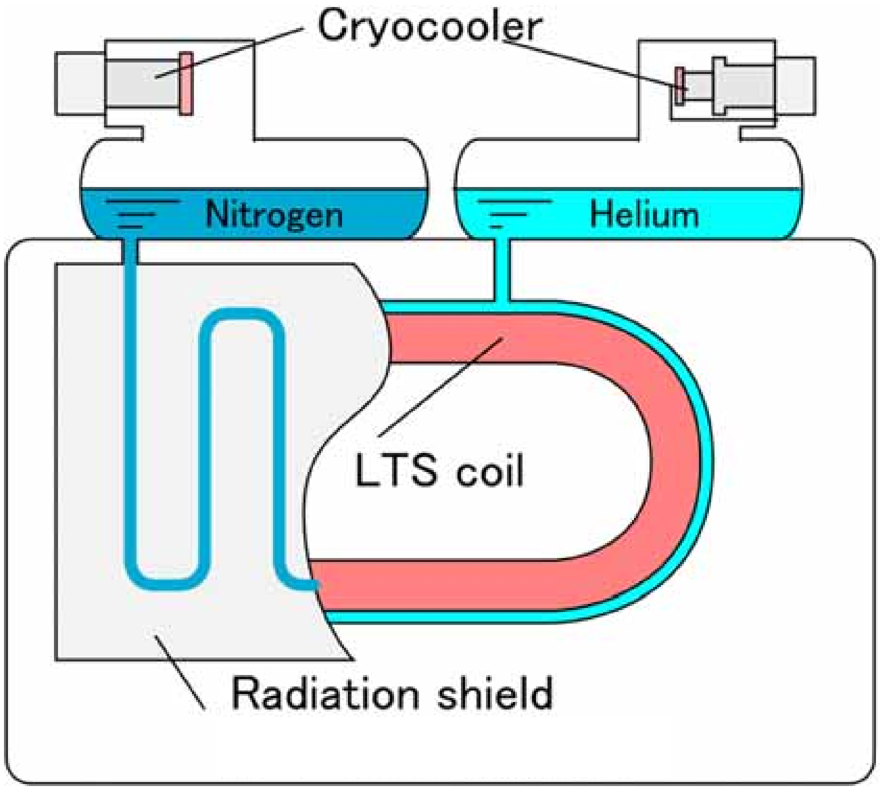
Inner vessel

Superconducting coil -------------- → Higher stability

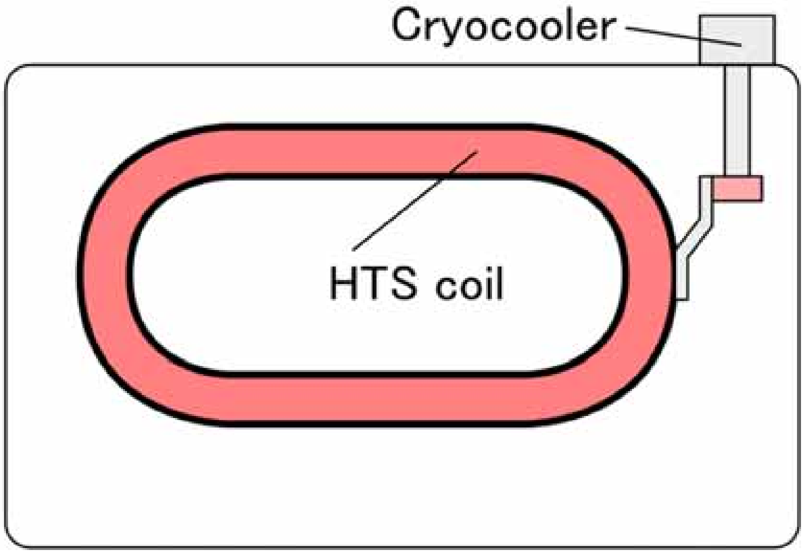
HTS magnet



Cooling System for HTS Magnet



Cooling system for a LTS magnet

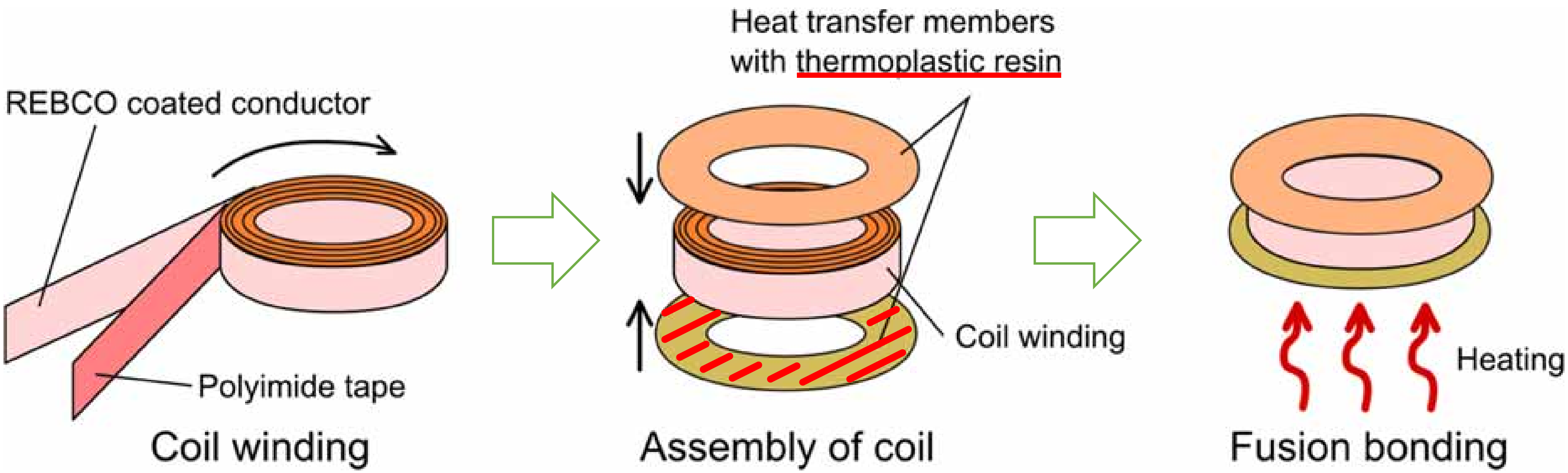


Cooling system for a HTS magnet

- **Simplified and easy cooling system**
- **Lower energy consumption**

Pancake Coil Fabrication Process

The coil winding and heat transfer members are bonded with thermoplastic resin without impregnation.

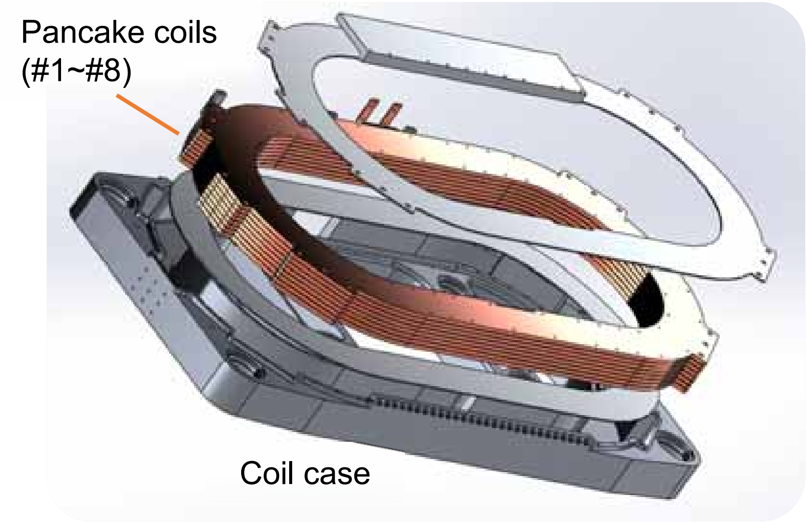


Quarterly Report of RTRI, Vol.57, No.3, p.234-239, 2016

Heating process melts the thermoplastic resin and bonds the components.
The thermoplastic resin does not infiltrate into the winding because of its high viscosity.

REBCO Superconducting Coil

Pancake coil



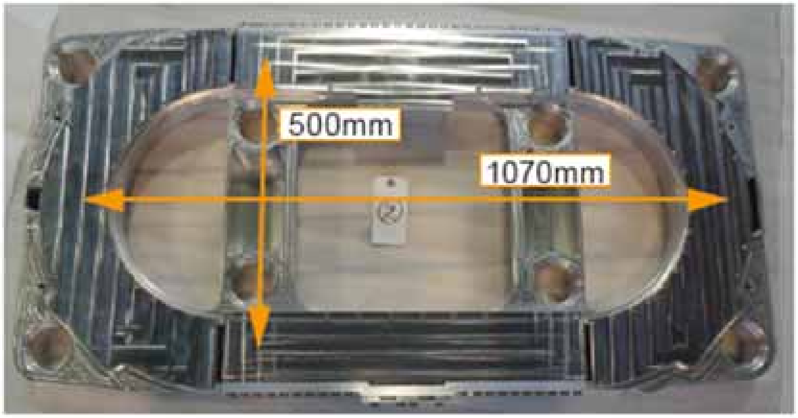
Assembly of the REBCO coil

IEEE Trans. Appl. Supercond., Vol.27, No.4, 2017, 3600205

Specifications of the REBCO coil

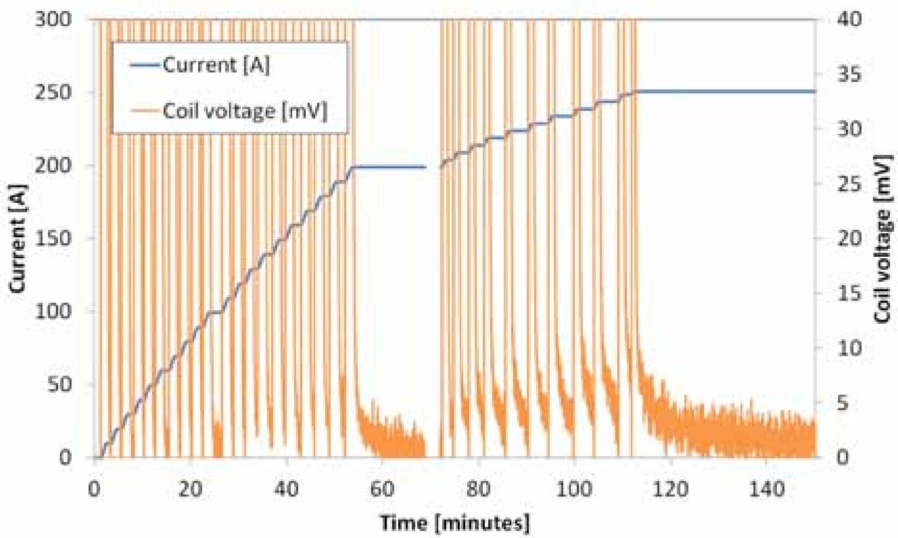
Operating current	250 A
Magnetomotive force	700 kA
Stacking number of pancake coils	8
Number of turns	2800
Total wire length	7600 m
Inductance	12 H

Current is supplied an external power supply.



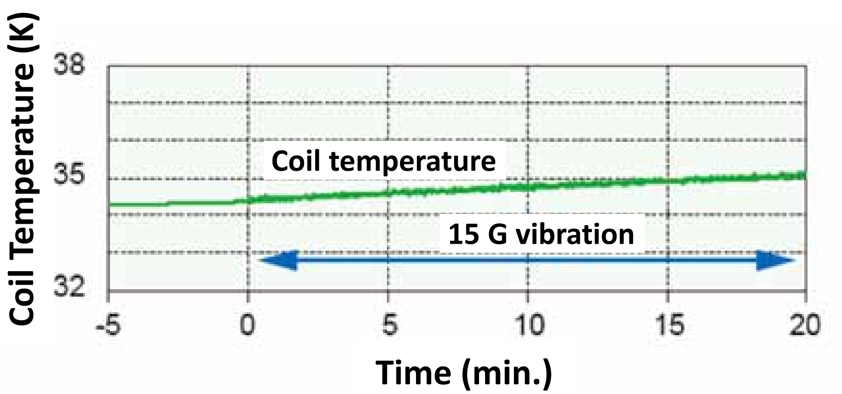
http://www.rtri.or.jp/rd/seika/2016/5-29.html

Excitation Test Results of REBCO Coil



RTRI REPORT, Vol.31, No.1, pp.5-10, 2017

Current : **250 A**
Magnetomotive force : **700 kA**
Max. flux density : **5.2 T**



Vibration test of 700 kA REBCO coil

- ✓ **15 G vibration acceleration of the 1st bending mode for 20 min.**
- ✓ **12 % increase in heat load**

http://www.rtri.or.jp/rd/seika/2016/5-29.html

The magnetomotive force of 700 kA was achieved at 35 K.

On-board Power Supply: Inductive Power Collection

An on-board power supply for supplying electricity to a refrigeration system for superconducting magnets, an air-conditioning system, a lighting system, etc. in the vehicles.

Gas turbine engine generator

It contributed a lot to a stable and reliable operation of superconducting maglev system in the period from 1997.

↓

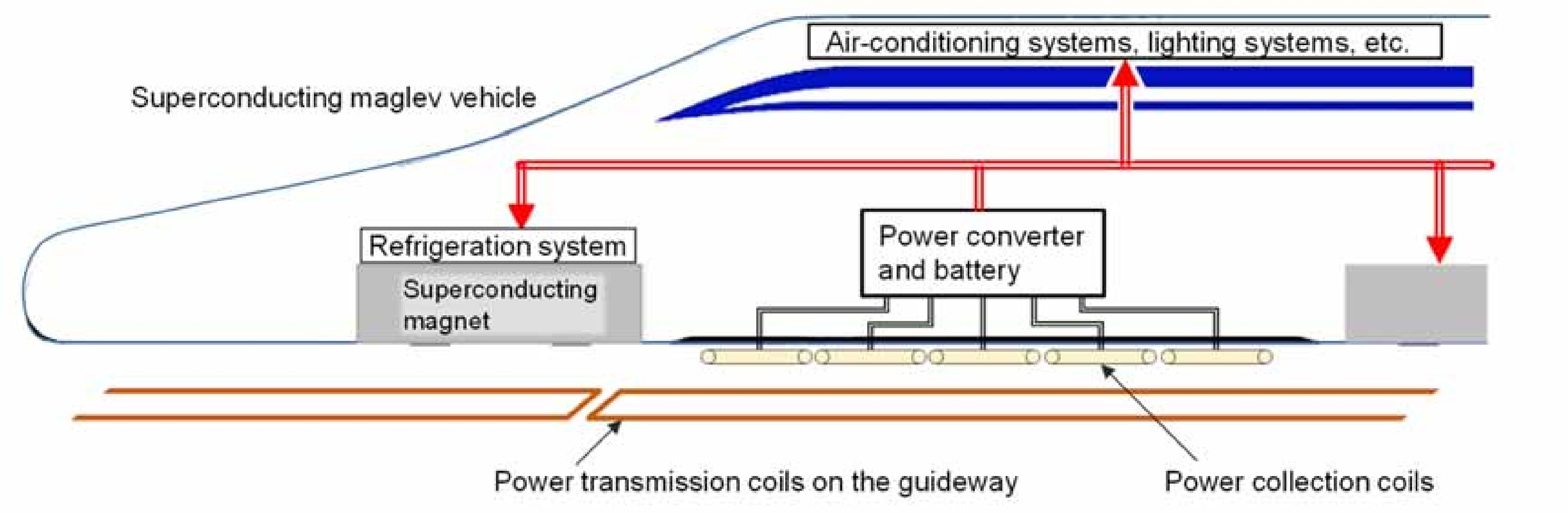
Inductive power collection

On-board Power Supply: Inductive Power Collection

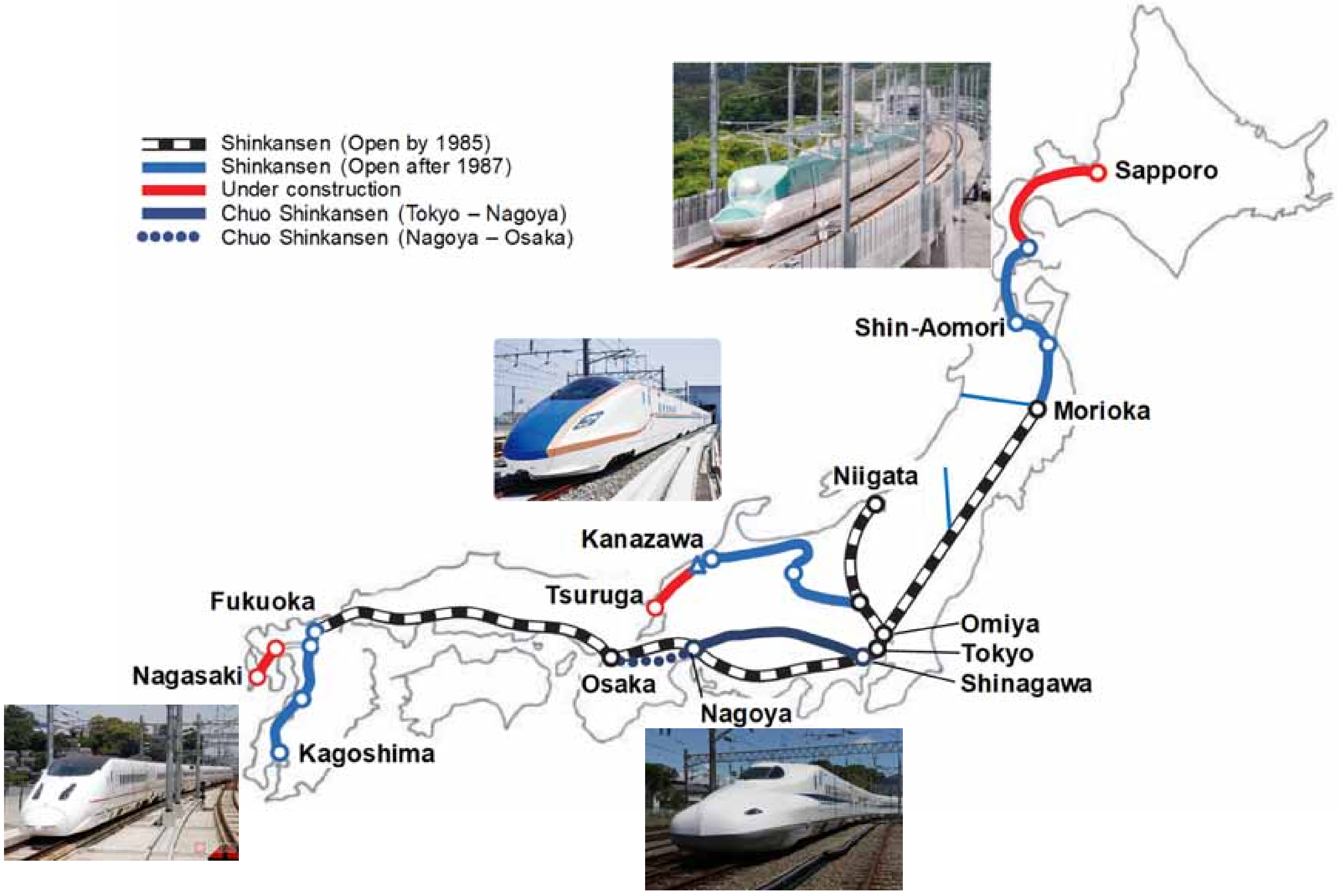
An on-board power supply for supplying electricity to a refrigeration system for superconducting magnets, an air-conditioning system, a lighting system, etc. in the vehicles.

Inductive power collection

The most characteristic point is high-power inductive power collection at very high speeds and with a large air gap



JR Shinkansen Lines



Chuo Shinkansen between Tokyo and Osaka

Chuo Shinkansen operated with the superconducting maglev system between Tokyo and Osaka

The Chuo Shinkansen was planned as the Tokaido Shinkansen Bypass connecting three major metropolitan areas in Japan: Tokyo, Nagoya and Osaka.

- Almost upper limit of the passenger transport capacity of Tokaido Shinkansen
- In preparation for natural disasters (big earthquake)
- 50 years operation of Tokaido Shinkansen. Full maintenance will be needed.

Chuo Shinkansen between Tokyo and Osaka

2014	October	The construction project was approved by the MLIT.
	December	JR Central started the construction between Tokyo and Nagoya.
2015	September	Full construction of Shinagawa Station in Tokyo started. About 40 m underground below the existing Tokaido Shinkansen Shinagawa Station.

Construction of Shinagawa station, Nagoya station, and Tunnel in the South Alps of Japan.

Chuo Shinkansen operated with the superconducting maglev system between Tokyo and Osaka

Shinkansen	Chuo Shinkansen (2027 -)	Chuo Shinkansen (2045 -)	Tokaido Shinkansen
Route	Tokyo - Nagoya	Tokyo - Osaka	Tokyo – Osaka
Length	286 km	438 km	515 km
Journey time	40 min.	67 min.	142 min.
Max. speed	505 km/h	505 km/h	285 km/h
Construction cost incl. train cars	5.5 trillion yen	9 trillion yen	-

*In the present plan of the Chuo Shinkansen using the superconducting maglev system, about **87 %** of the route between Tokyo and Nagoya is **in tunnel sections**.*

Master Plan for Technology Development

Master Plan from FY 1990 to FY 2016

- Verification of long-term durability
- Cost reduction including maintenance cost
- Equipment Spec for the commercial line
- Inspection under the energized superconducting magnet condition
- Inductive power collection system for on-board power supply

6 years extension

Master Plan from FY 1990 to FY 2022

- Verification of low-cost and efficient maintenance system
- Verification of long-term durability of high-temperature superconducting magnets
- Improvement of passenger comfort

FY2027 Commercial Operation between Tokyo and Nagoya (290 km)

Summary

- **The superconducting maglev technology and the recent situation of Chuo Shinkansen development for commercial service were presented.**
- **The superconducting maglev system technology for the Chuo Shinkansen between Tokyo and Nagoya is ready, and the construction started.**
- **The Chuo Shinkansen will be opened in 2027.**
- **There are many tunnels including deep underground in the metropolitan areas.**
- **After the construction of the commercial line started, technology development for cost reduction, reduced maintenance, improved system stability, etc. should continue.**
- **It is also expected that the extension of the line to Osaka should be realized earlier than in 2045.**