

# **Review and update on MAGLEV**

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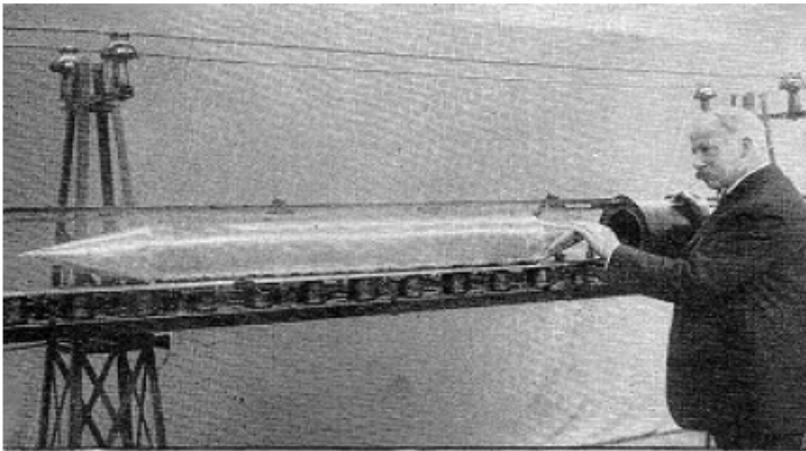
## *Review and update on MAGLEV*

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- 2. Superconducting Magnet**
- 3. History of Superconducting Maglev Development in Japan**
- 4. Progresses of Superconducting Maglev Technologies**
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# Invention of ElectroDynamic Suspension (EDS)

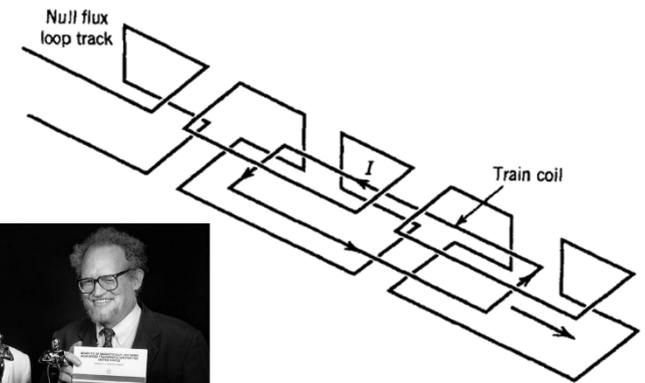
- In 1912 Emile Bachelet invented **magnetically levitating** transmitting apparatus and displayed a model. (EDS)
- In 1968 J. Powell and G. Danby proposed a new type of magnetic suspension, the null flux suspension.

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



Der Erfinder läßt den Wogen der Schnellbahn ablaufen.

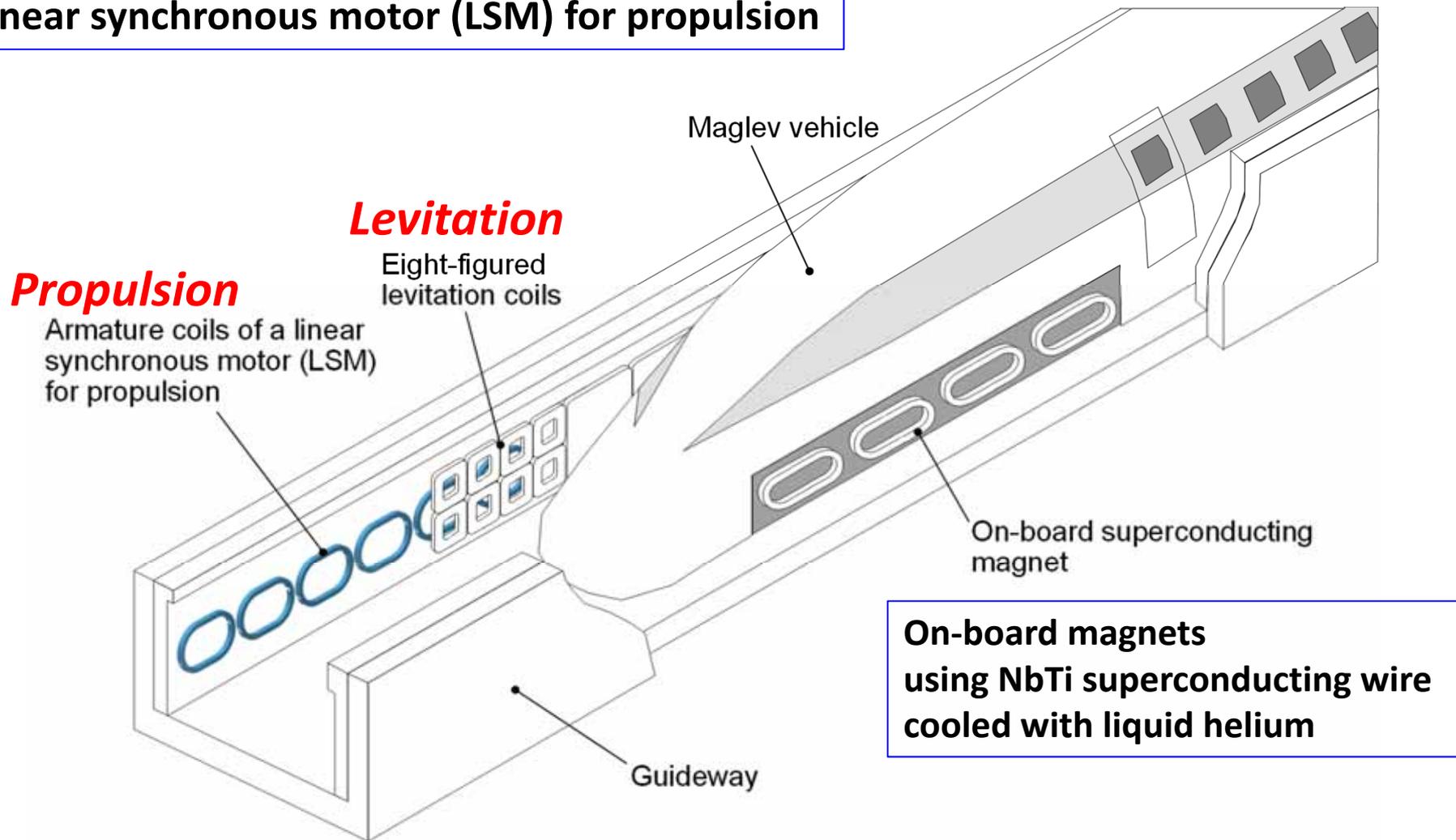
Emile Bachelet with his maglev model. He obtained an U.S. patent for levitating transmitting apparatus in 1912. <EDS>



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



# Magnetic Levitation – ElectroDynamic Suspension

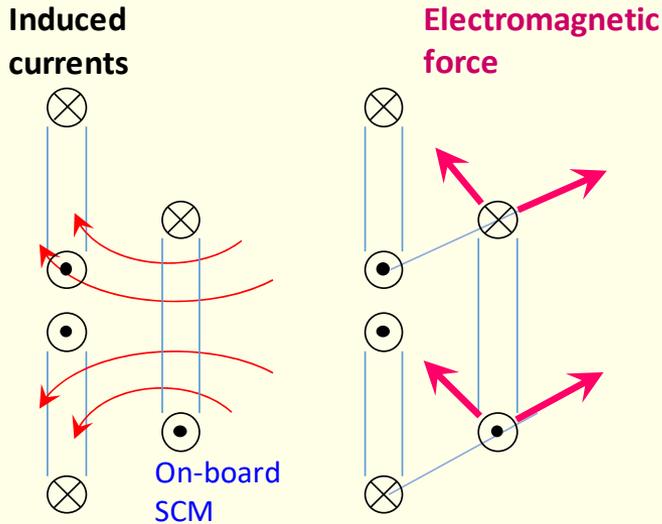
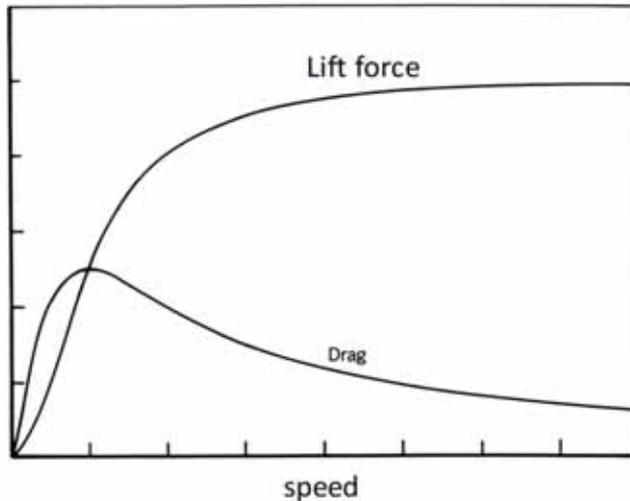
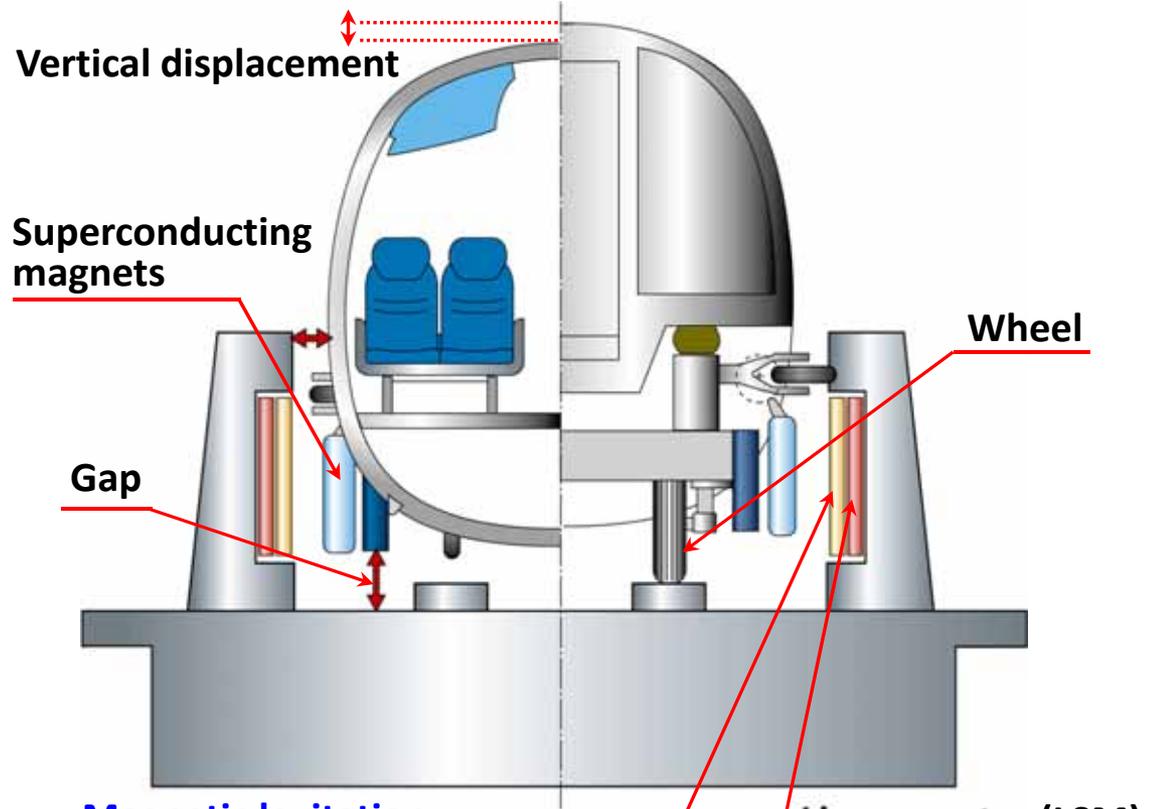


Figure-eight levitation coils on the ground **ElectroDynamic Suspension (EDS)**



**Magnetic levitation at high speeds**

**Travel with wheels at low speeds**

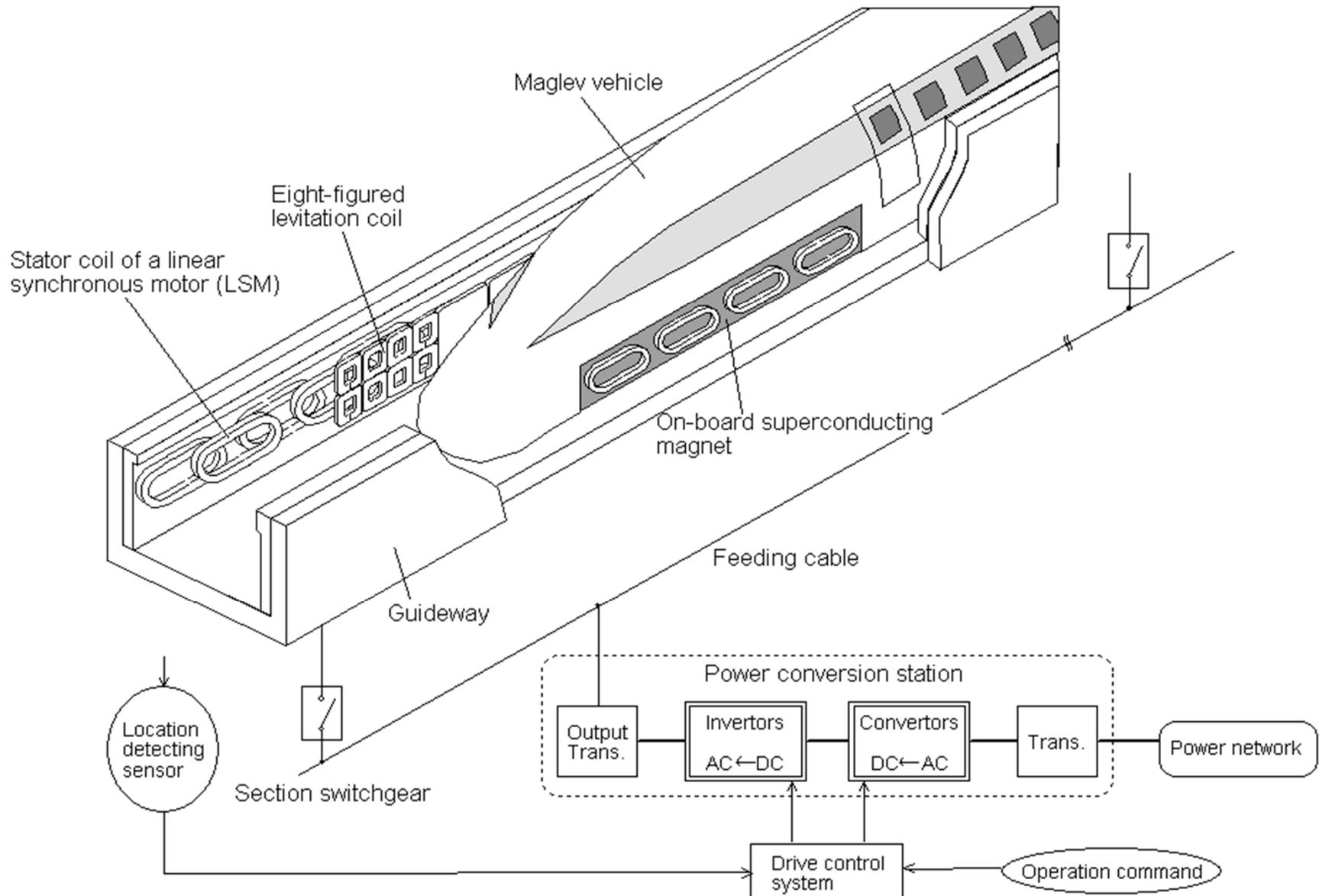


Magnetic levitation  
 Speeds > 120 ~ 130 km/h  
 Gap about 10 cm  
 No gap control

Linear motor (LSM)  
 Armature coils  
 Figure-eight Levitation coils



# 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

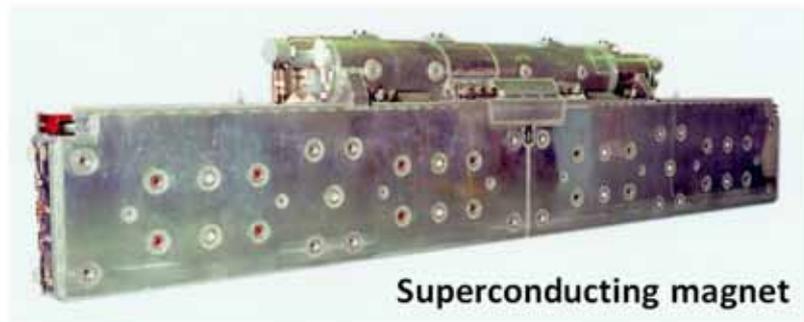
## Fundamental structure of the on-board superconducting magnet

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

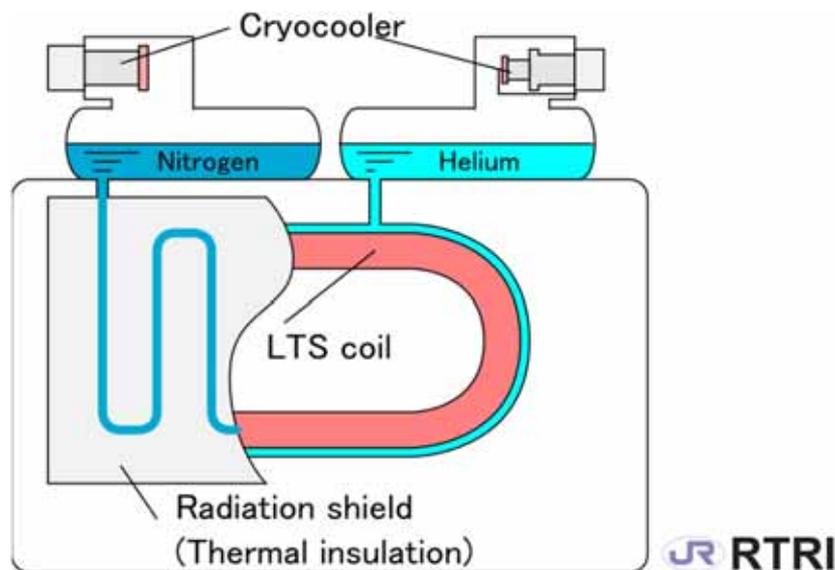
- ✓ Stable quench-free coil,
- ✓ Lower heat invasion,
- ✓ Reduced heat generation caused by electromagnetic and mechanical vibrations,
- ✓ Lightweight, etc.



# 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



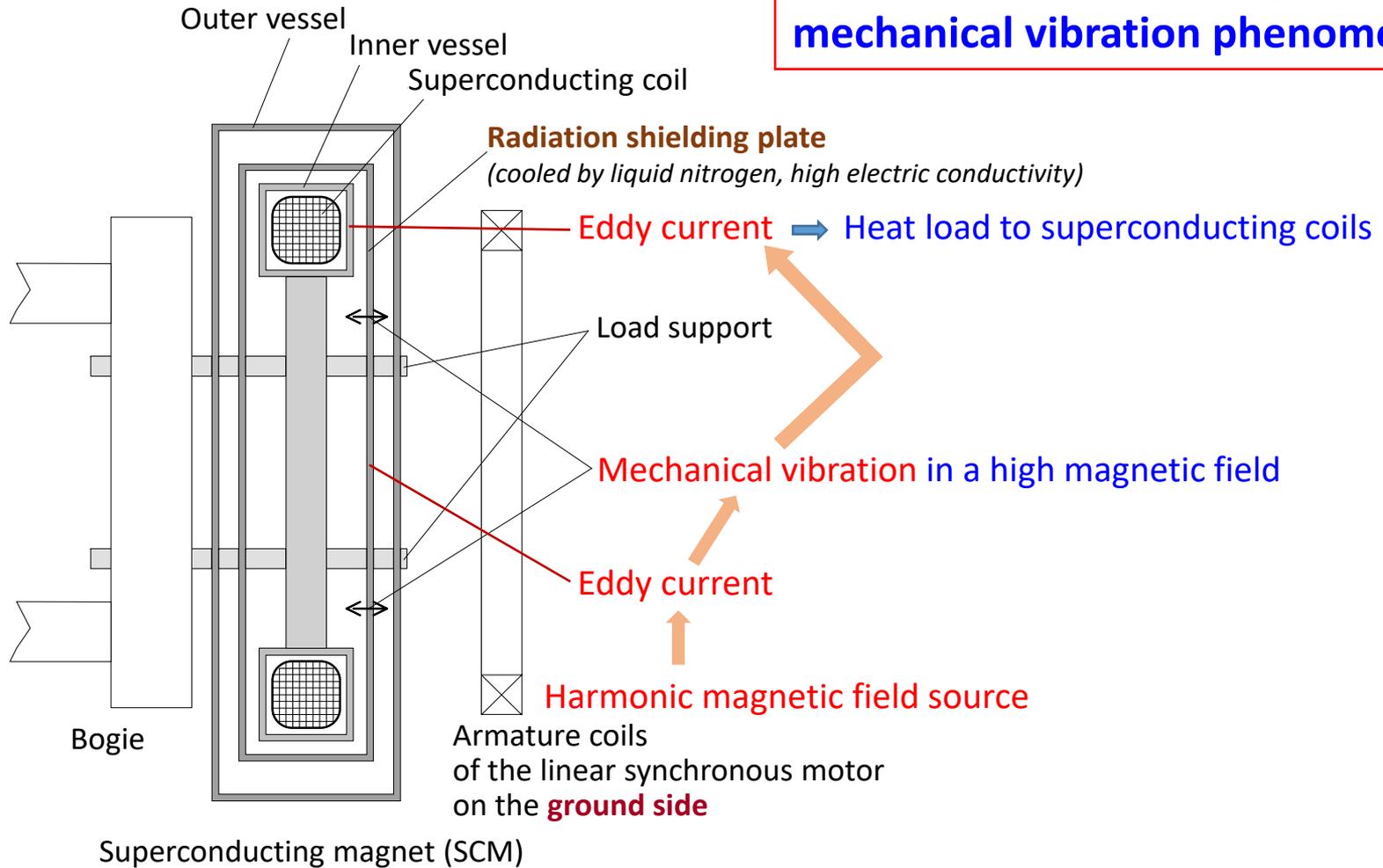
### Example of magnet specifications

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	<b>Yamanashi Test Line opened</b> , 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)

<b>2007</b>	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
<b>2009</b>	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.”
<b>2010</b>	In April 2010, the JR Central pushed back the schedule for the start of operations of the Chuo Shinkansen from 2025 to 2027.
<b>2011</b>	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)

<b>2011</b>	(in September) Running test ended at the Yamanashi test line. The total running distance was about 874000 km. Test Track Extension and Facility Replacement.	
<b>2013</b>	Extension of Yamanashi Test Line completed (42.8 km) Running tests restarted using the L0 type new vehicle.	
<b>2014</b>	(in October) Approval of the construction implementation plan of the Chuo Shinkansen between Shinagawa and Nagoya. (in December) Construction of the Chuo Shinkansen started.	
<b>2015</b>	(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.	
<b>2027</b>	Commercial operation between Tokyo and Nagoya (290 km)	
<b>2045</b>	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**

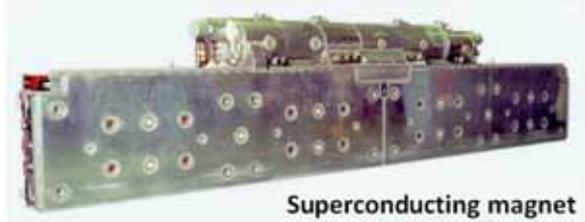


# Superconducting Magnet using Bi2223 wire

- 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)



Superconducting magnet

Onboard refrigerator

Liquid helium tank -----> **Removed**

Liquid nitrogen tank -----> **Removed**

Outer vessel -----> **Thinner**

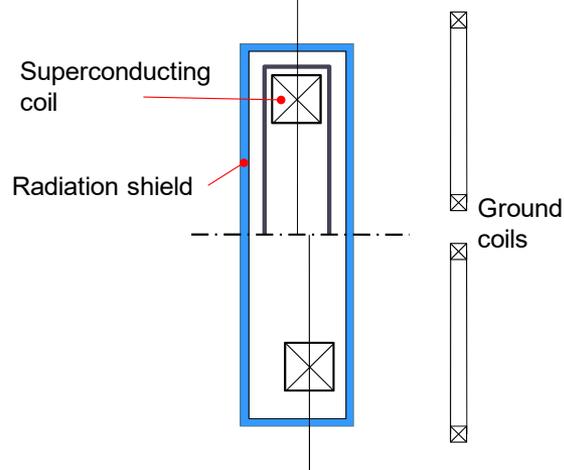
Radiation shield plate -----> **Removed**

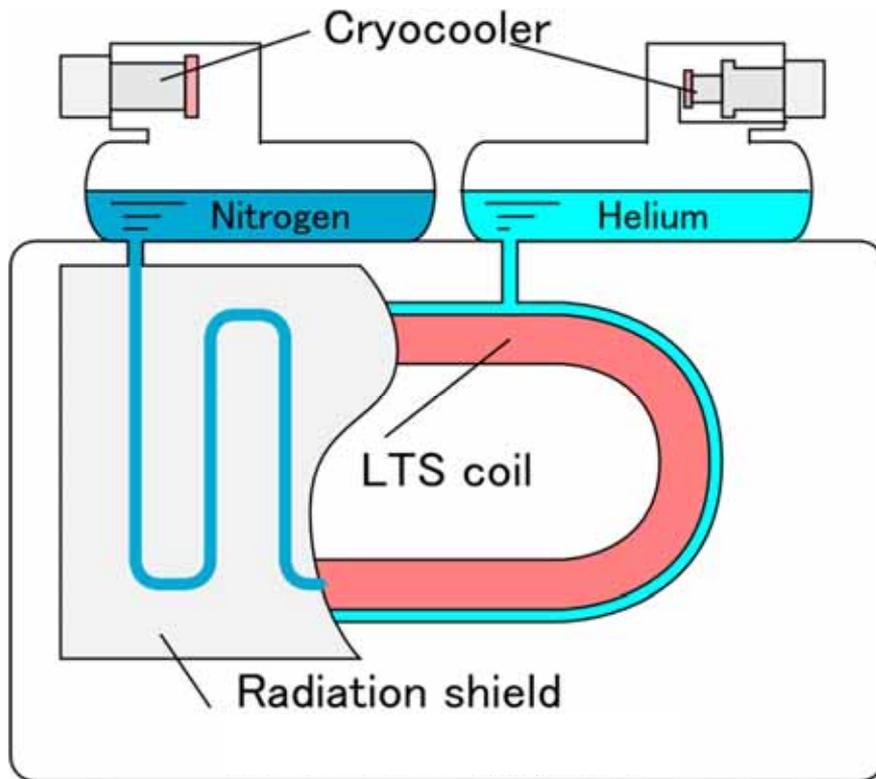
Inner vessel

Superconducting coil -----> **Higher stability**

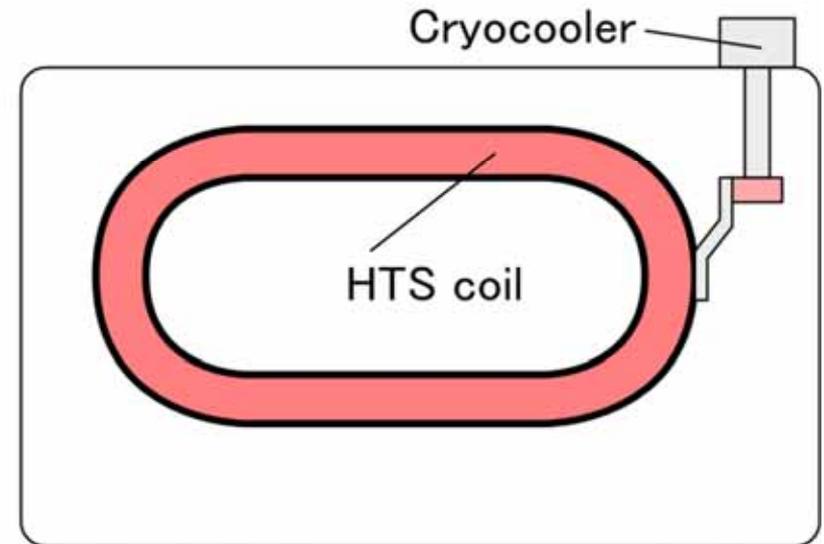
More compact, lighter weight  
Reduced input power

### HTS magnet





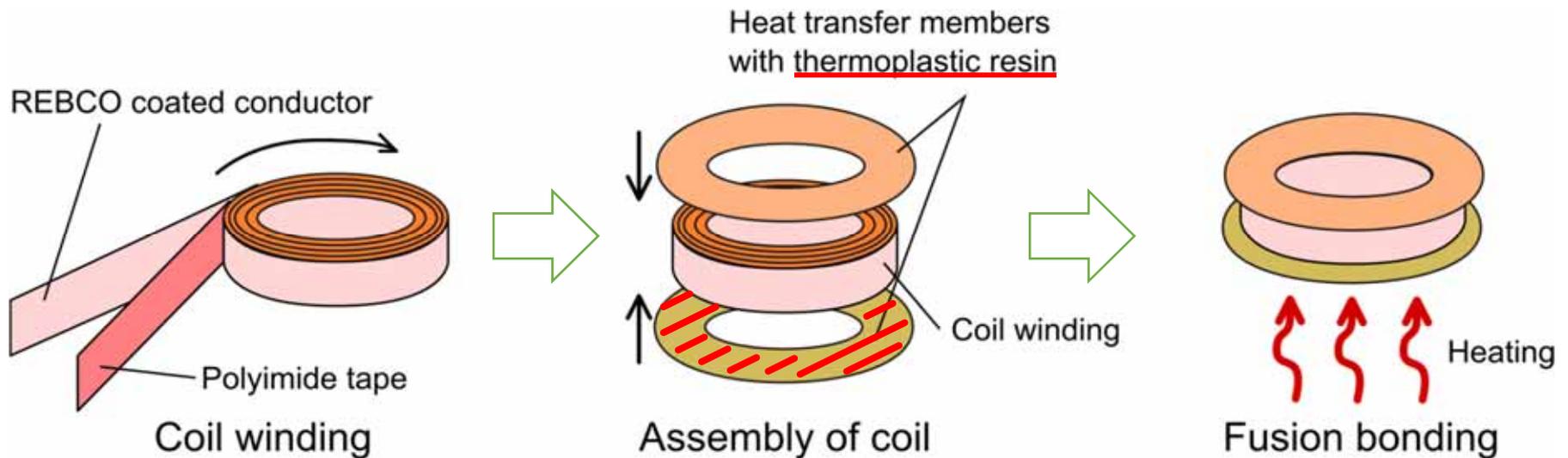
Cooling system for a LTS magnet



Cooling system for a HTS magnet

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

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

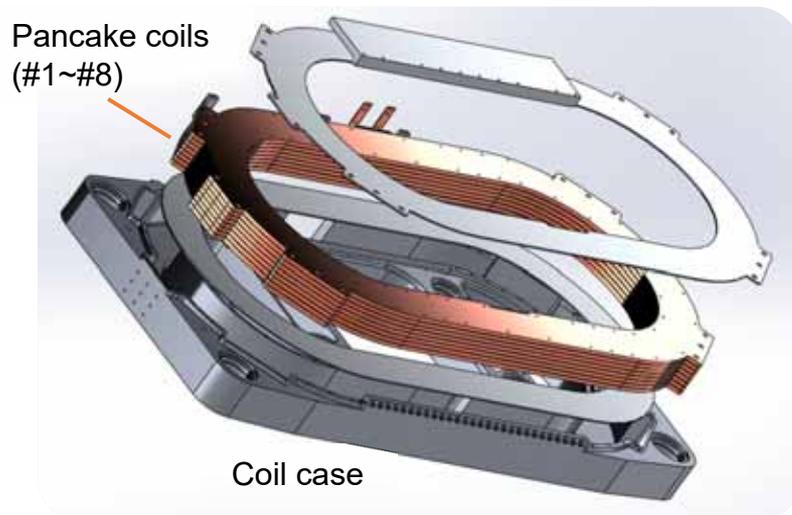


*Quarterly Report of RTRI, Vol.57, No.3, p.234-239, 2016*

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



Pancake coil

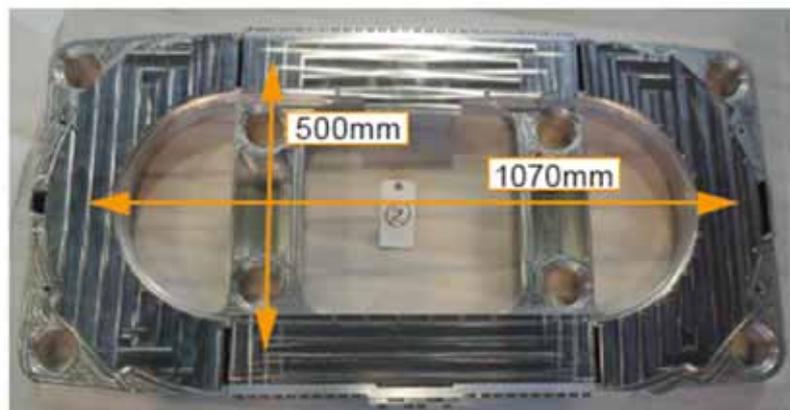


Assembly of the REBCO coil

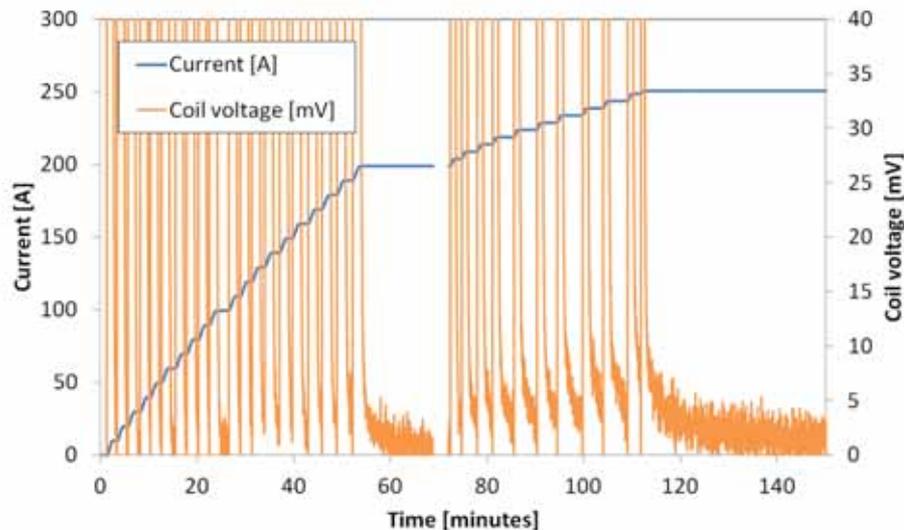
## Specifications of the REBCO coil

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

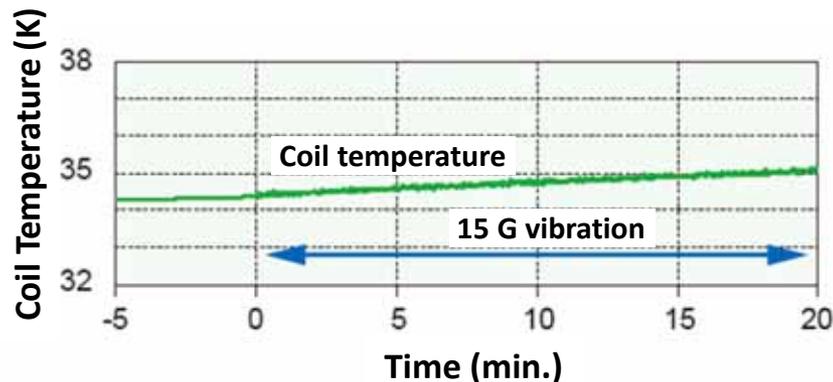
*Current is supplied an external power supply.*



# 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 1<sup>st</sup> bending mode for 20 min.  
✓ 12 % increase in heat load

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

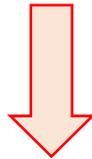
The magnetomotive force of **700 kA** was achieved at **35 K**.

# 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.*



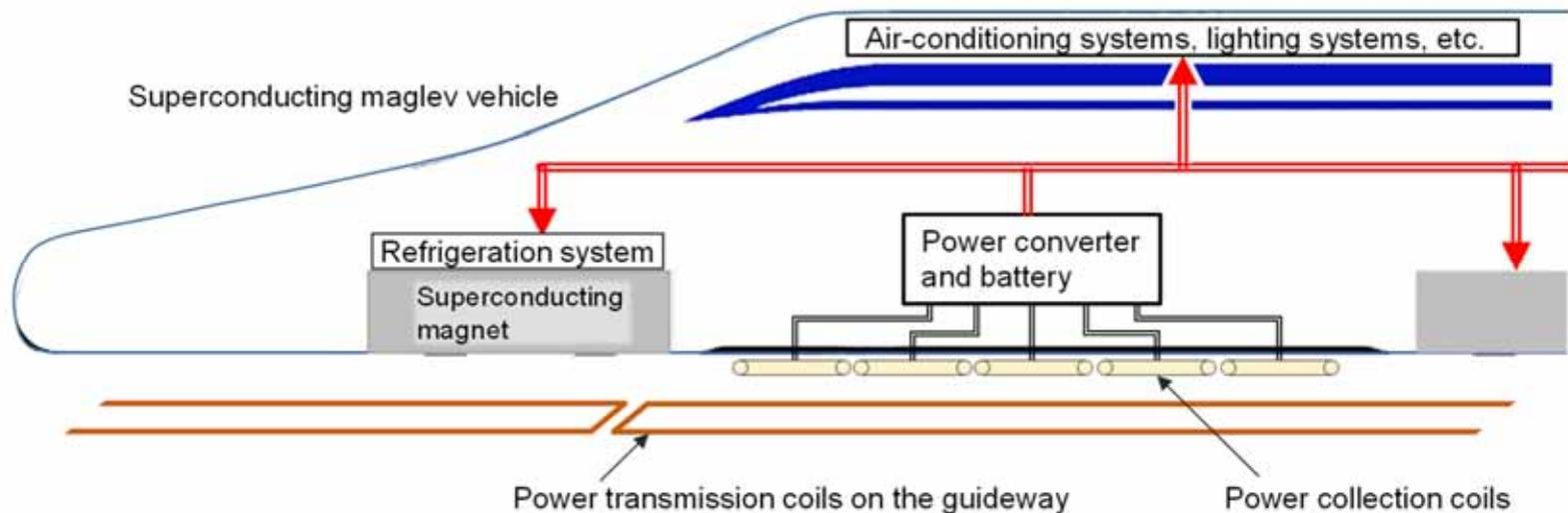
**Inductive power collection**

# 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.

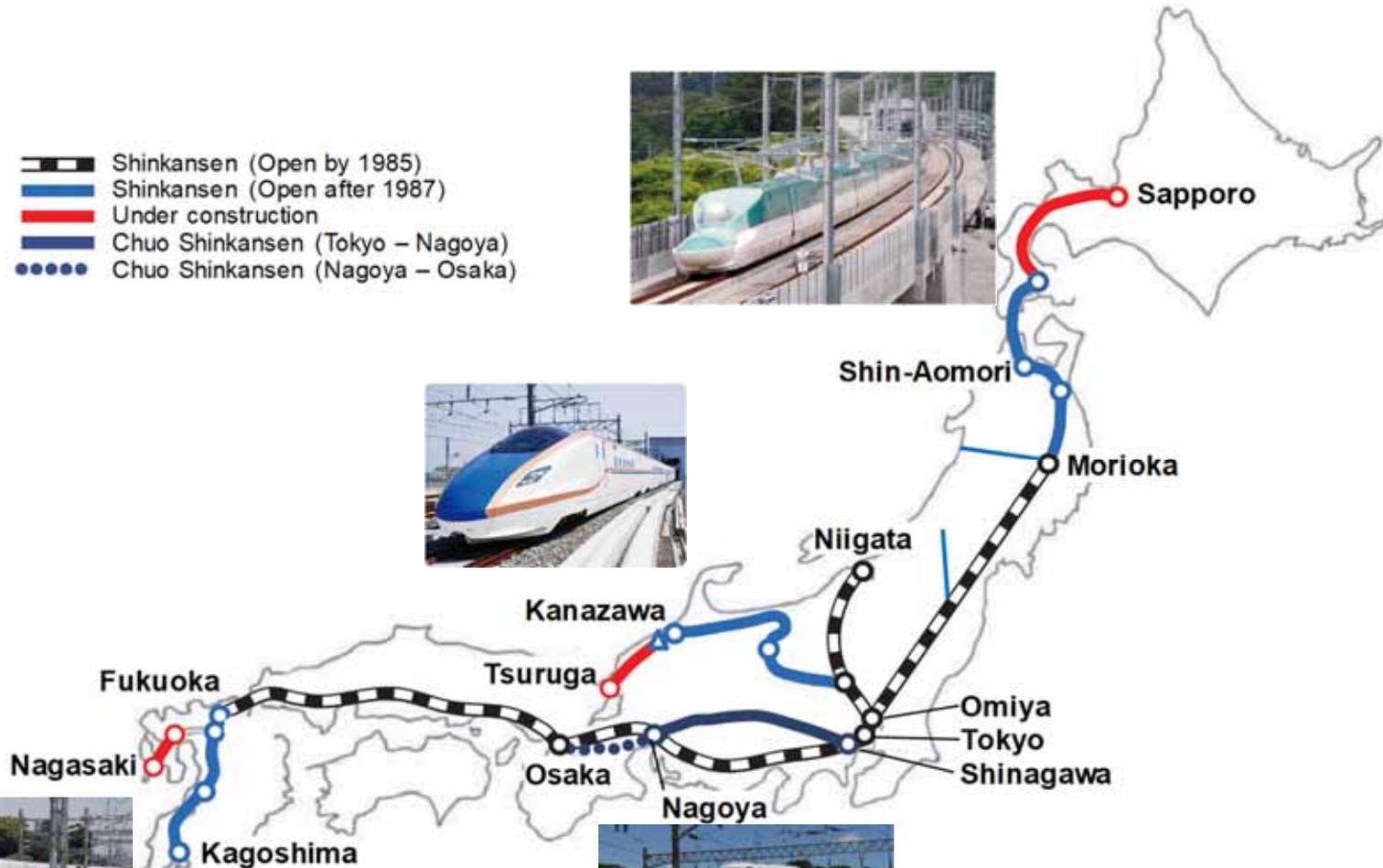
## Inductive power collection

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



# JR Shinkansen Lines

- ▬ Shinkansen (Open by 1985)
- ▬ Shinkansen (Open after 1987)
- ▬ Under construction
- ▬ Chuo Shinkansen (Tokyo – Nagoya)
- Chuo Shinkansen (Nagoya – Osaka)



# 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.**

