Deutsche Kälte- und Klimatagung DKV Deutscher Kälte- und Klimatechnischer Verein

16. – 18. November 2022, Magdeburg

Mobile Kryotechnik mit Supraleitern für Schwebezüge

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Content
1. Motivation
2. Maglev physics
3. Maglev-scaling load and speed
4. Conclusion

Transportation, industry, heating and cooling make up the lion's share of greenhouse gas emissions!
Lets do it progress with HTS, sooner than later!

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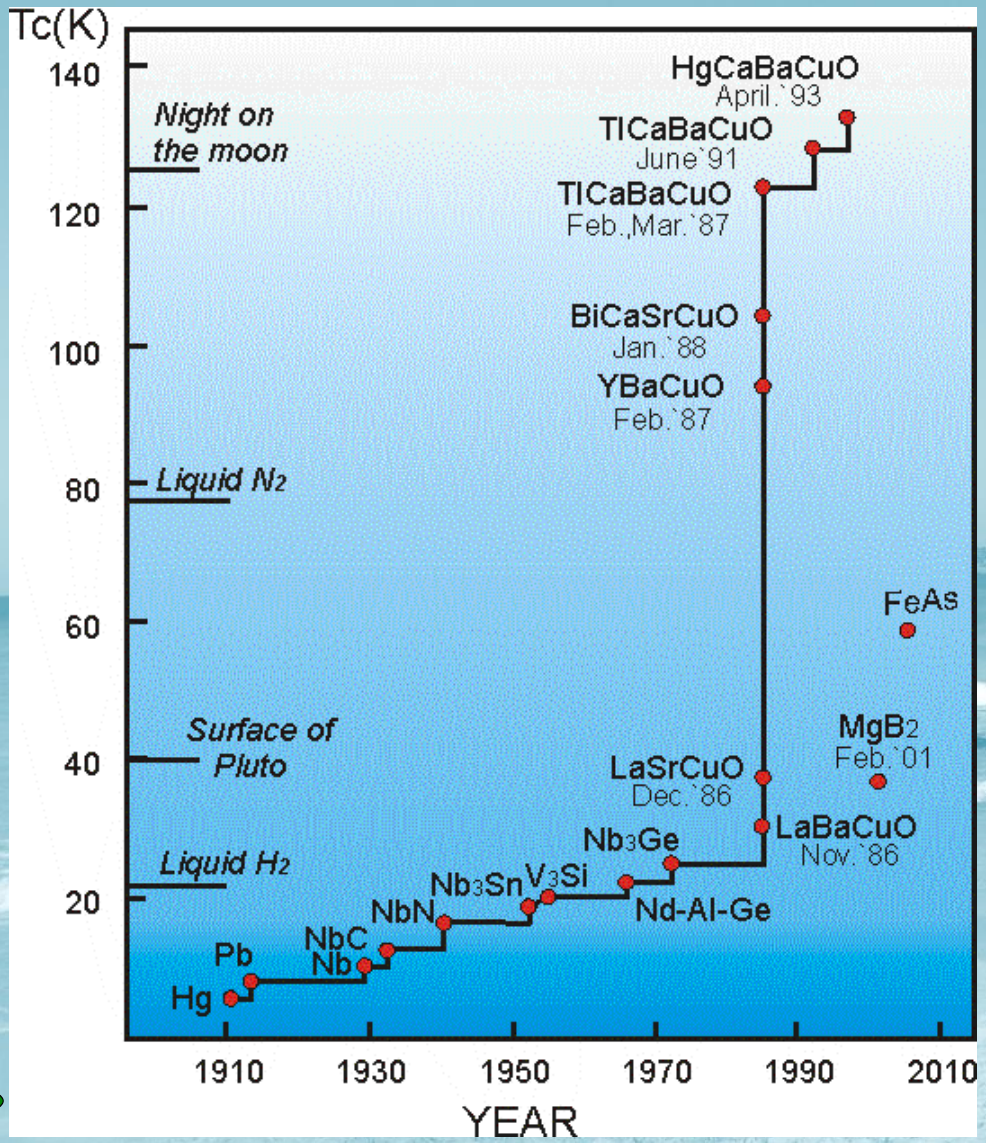
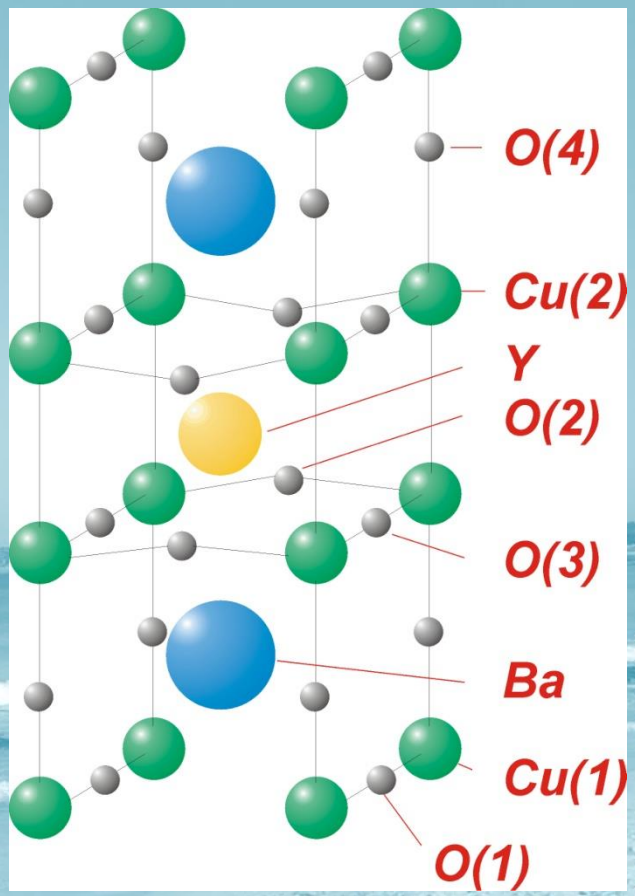
CELEBRATED ON NOV. 7, 2022 THE 30th ANNIVERSARY OF FOUNDING!

30th YEARS ANNIVERSARY

History of Superconductors





ReBa2Cu3O7-δ (RE123) crystalline structure
RE= Y, Sm, Gd, Dy, Nd, …

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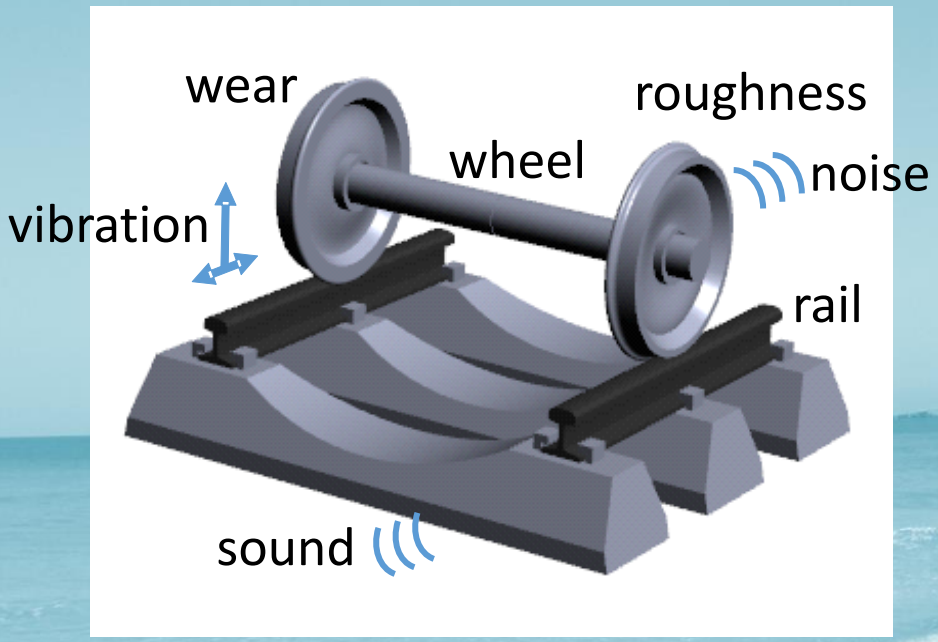
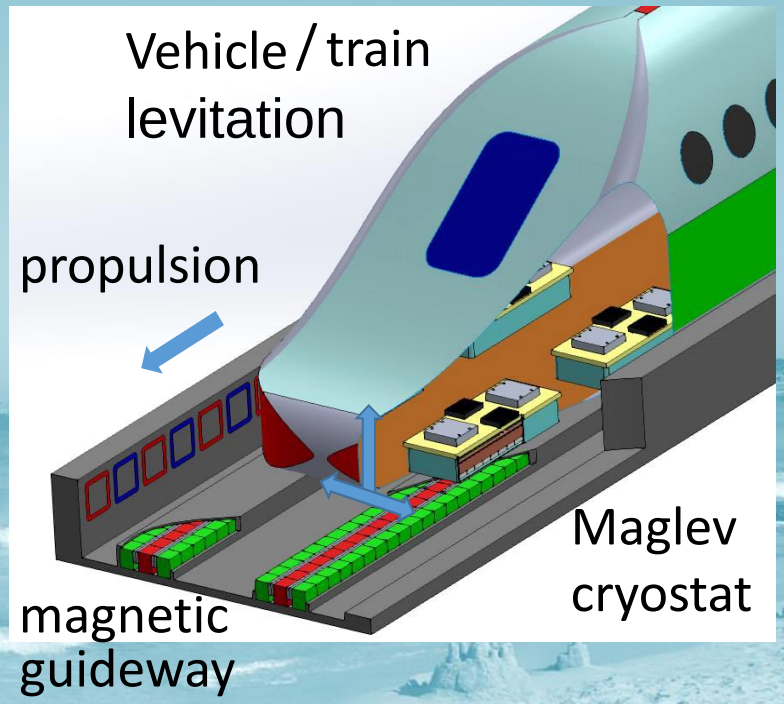
1. Motivation

Traditional wheel-rail configuration



New Maglev train



The cliche „Necessity is the mother of invention“ is no less true today. We have sampled here a specific Maglev application, just to illustrate the more general point, that HTS bulks enable clever technologies

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Maglev trains in operation and tests

USA-
Northeast

Germany
Switzerland
Italy
France

HTS

Russia

Korea

China

Vietnam

Japan

Brazil

20 Passengers

In operation
- HSST in Nagoya, Japan
- Transrapid Shanghai, China
- UTM, Korea
- Chuo Shinkansen, test line, Japan

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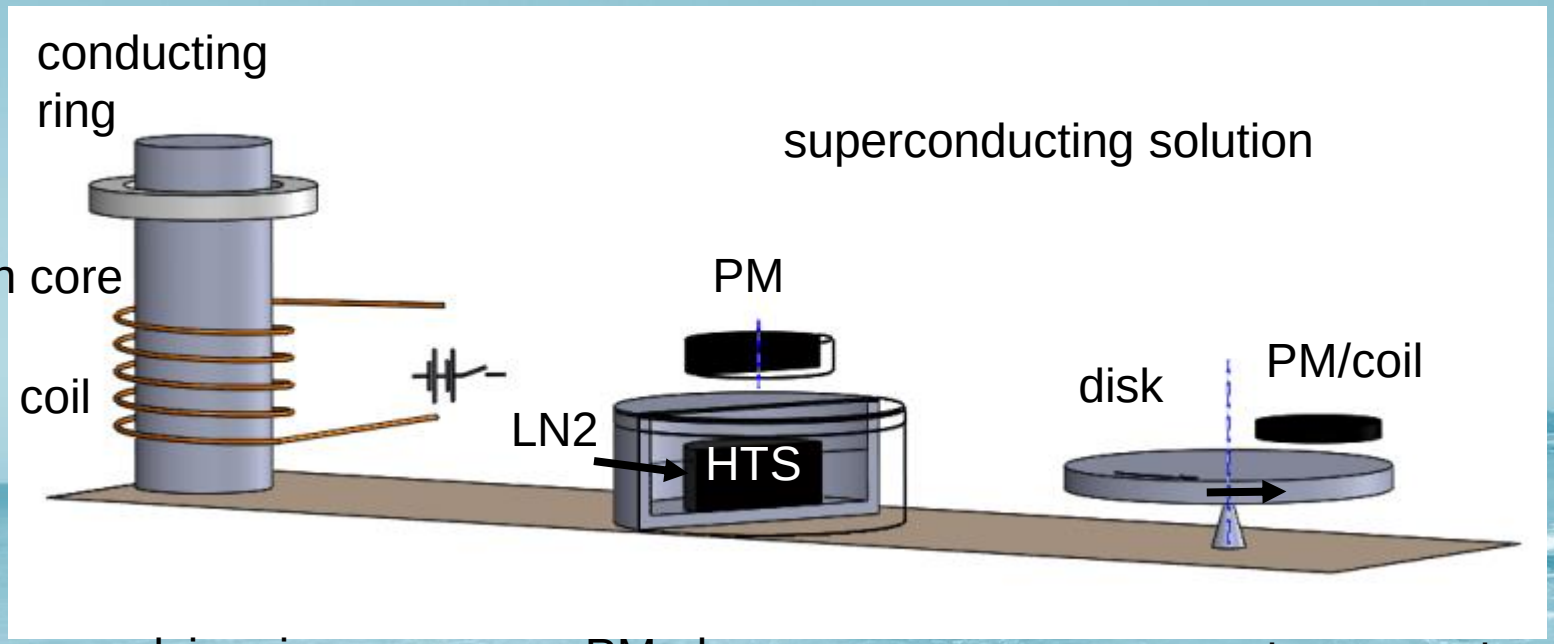
2. Maglev Physics

Magnetic Levitation - Maglev Ground Transportation



repulsive ring, Lenz's law	PM above cooled HTS bulk flux pinning	Magnet above rotating disk- eddy currents induced magnetic image
EMS	HTS Pinning	EDS
Transrapid/Germany	HTS Bulk/China	Chuo Shinkansen/Japan

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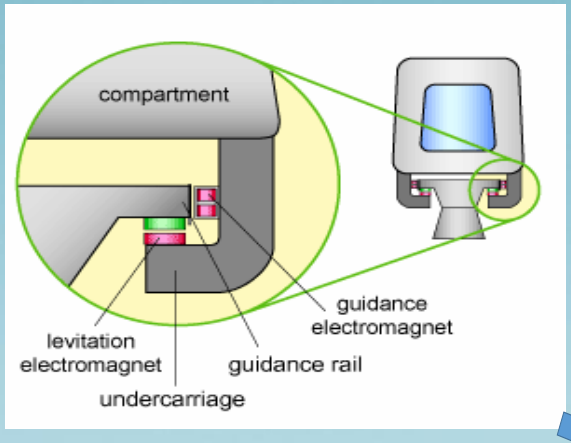
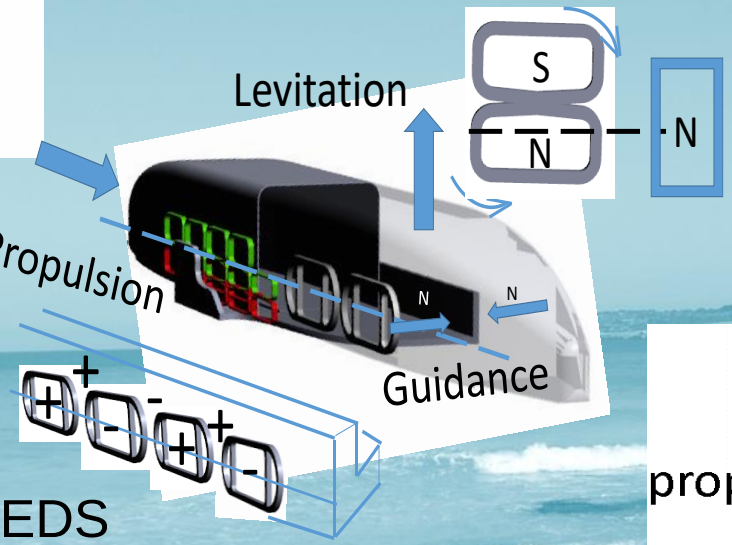
Magnetic train concepts

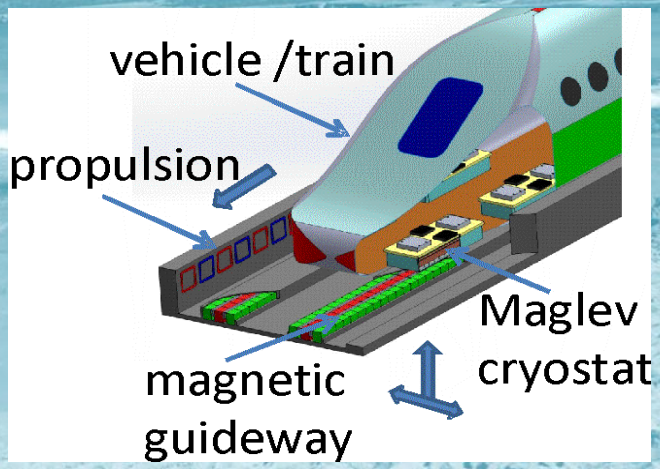


Electromagnetic EMS
(conv. Cu coils)
Established 400 km/h

Replacement ?



Electrodynamic EDS
(LTS presently, future HTS ?)
Established 500 km/h
Max. 603 km/h, 2015 test



HTS trapped field magnet
Demonstrator tests, 35 km/h
Target >400 km/h, p<100 mbar

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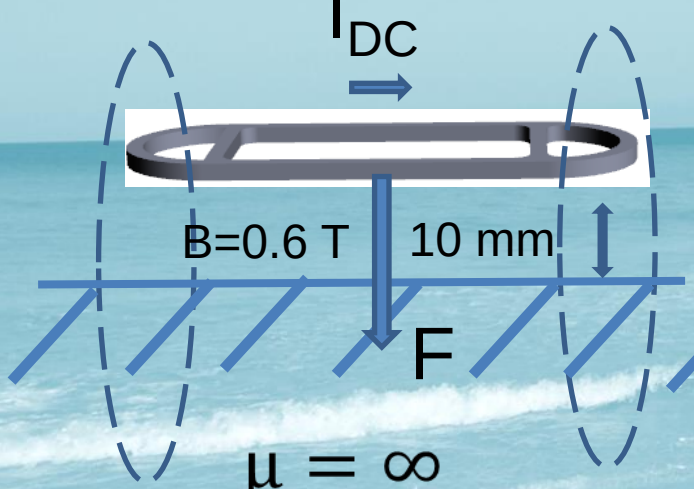
Operating trains

Electromagnetic suspension EMS (Cu)

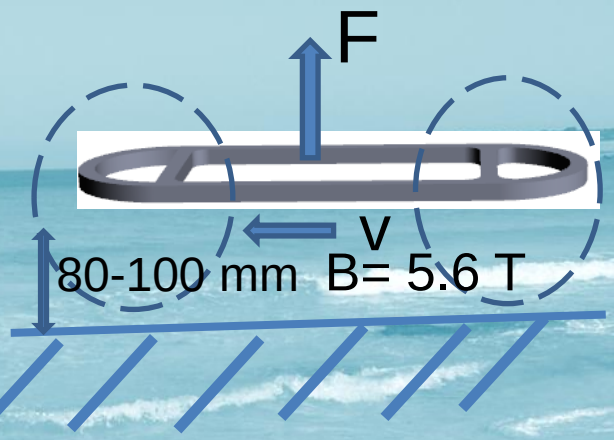


$\mu = \infty$

$\kappa = 0$

attractive

Electrodynamic suspension EDS (LTS superconductive)

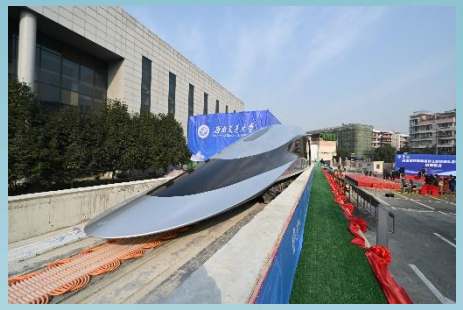


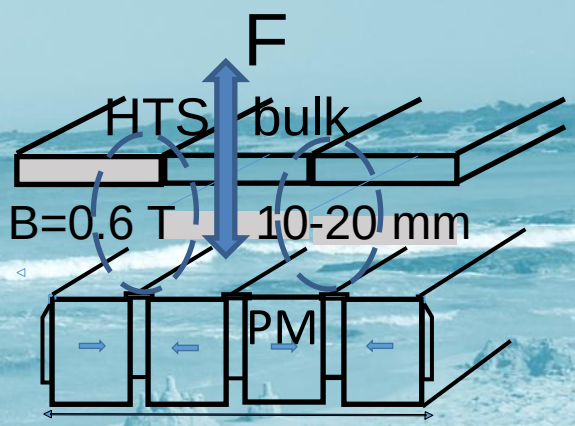
$\mu = \mu_0$

$\kappa = \infty$

repulsive

HTS bulk Maglev pinning levitation





$\mu = \mu_0$

$\kappa = \infty$

repulsive/attractive

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3. Maglev-scaling load and speed; Transrapid TR07

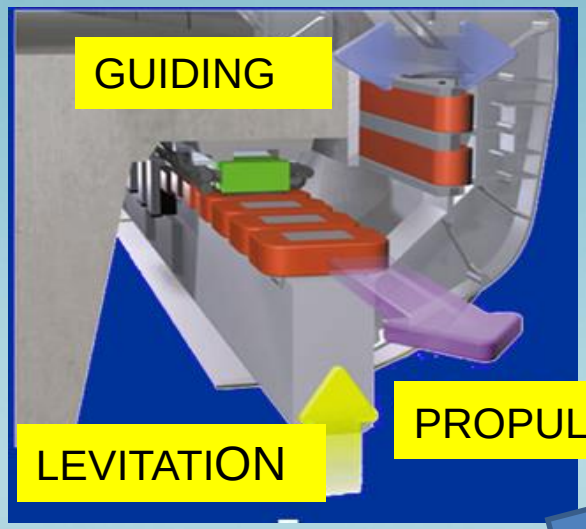

Fig. Montage TR07 Shanghai Transrapid

Magnetic energy, dW/ds = f (force)

$f=1/4\mu_0\, n^2\, A\, i^2/g^2$ A=200 cm²; i=50 A; n=10³ turns, g=8 cm

Levitation:

f=2,45 kN / coil; No of coils in TR07:180

Total suspension force f (180)= **90 ton!**

Vehicle mass**, m=80 mto**

Propulsion:

U_s= 4675 V, const. thrust up to 370 km/h,

$P_{max}=F \cdot v_{max}$; **P_{max} = 9.3 MW!**

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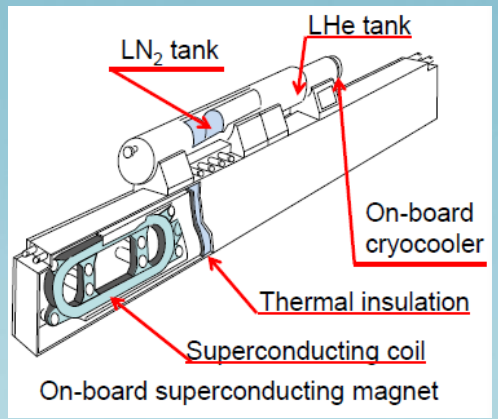
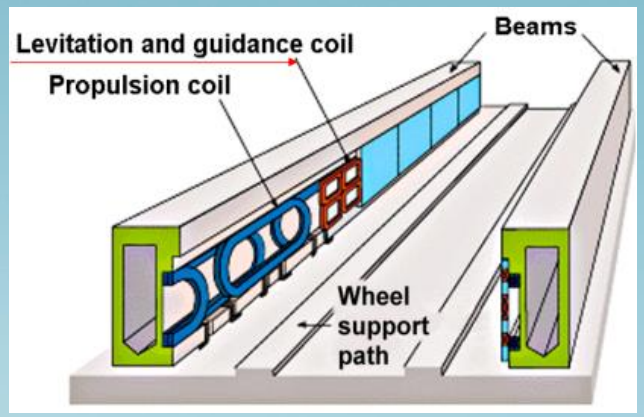
Ref. ThyssenKruppTransrapid

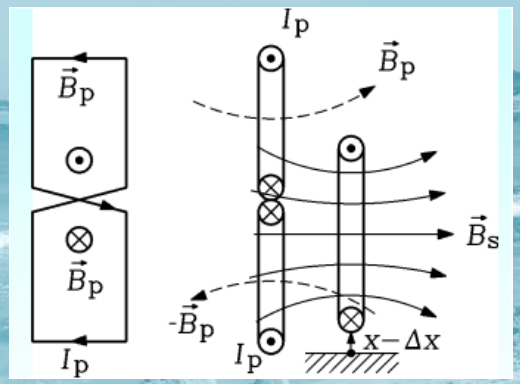
Yamanashi/ Chuo Shinkansen – Levitation, RTRI Tokyo, JP

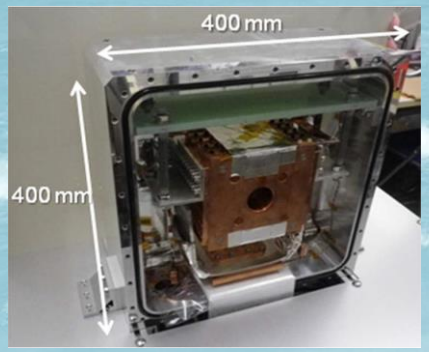




LTS

- Two cryostats, 4 x LTS DC coils per cryostat @ 4.2 K
- **Force 220 kN@43 mm** displacement
- NbTi –Multifilament coil (1167 turns), q=1x2.1mm²; I =600 A, I/q= 243 A/mm²





HTS wire (REBCO, BSCCO)
B = 5 T, 6 T @ 45 K
J_e/q = 130 A/mm², similar to LTS

K. Mizuno, IEEE Trans. Appl.Supercond.23,3(2013)
1Central Japan Railway Company, Tokyo, Japan
J. Kitano, Central Japan Railway Company, Progress of the Superconducting Maglev Chuo Shinkansen; WCRR 2019, report

LTS vs. HTS?

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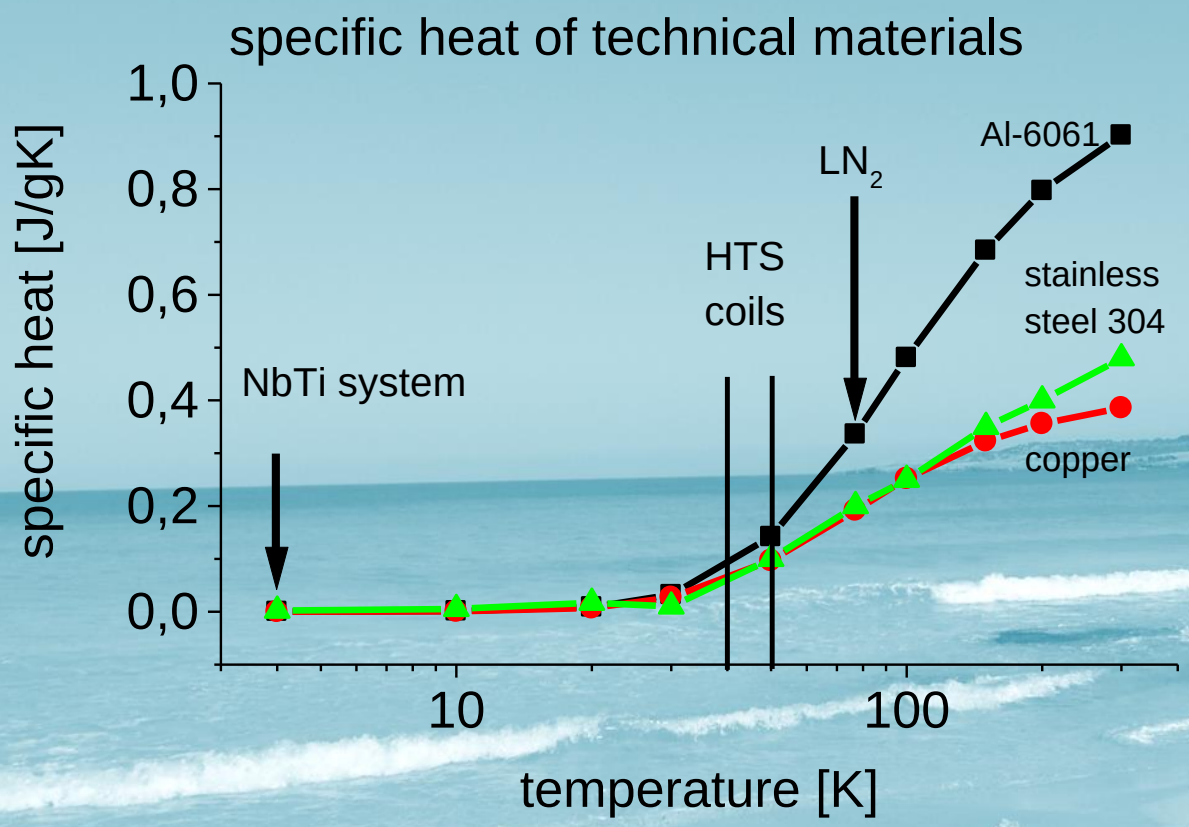
Maglev: LTS vs. HTS



Advantages of HTS compared to LTS:

- Improved thermal stability
- easier cryogenic process,
- lower energy for cooling

Fig.
HTS system will raise the operational temperature.

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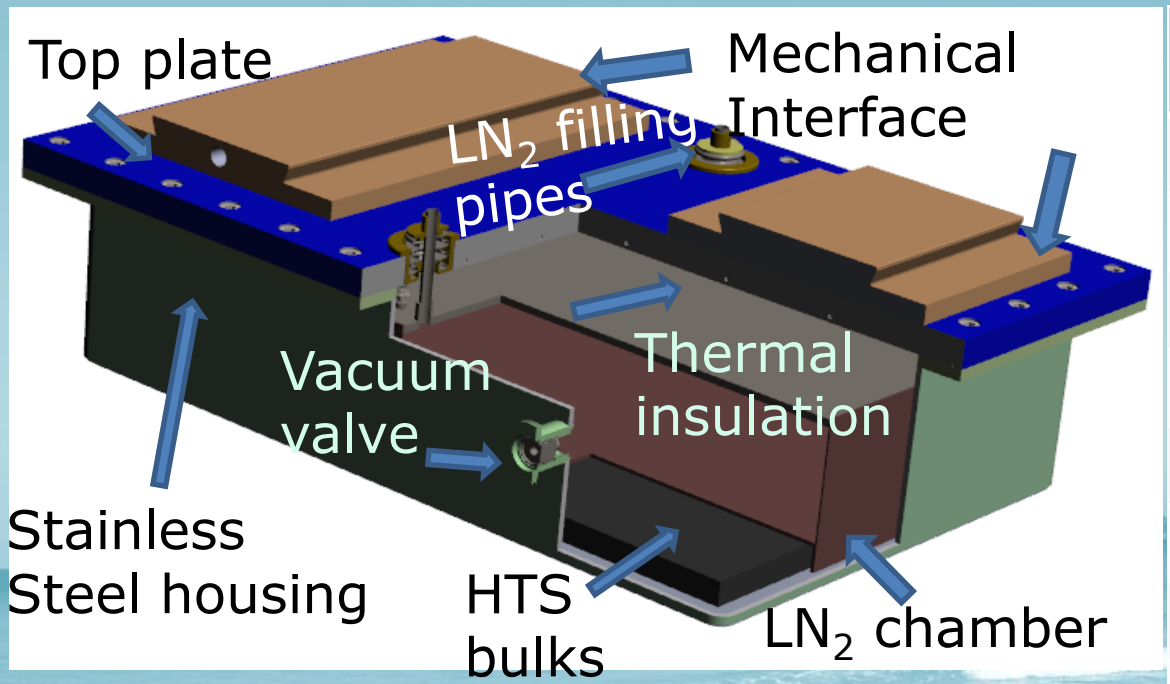
Cryostat/Magnet* design and construction (scaling load)



Component	Weight [grams]
Stainl. Steel housing	6060
Copper frame for HTS bulks	5366
YBCO bulks 80x40x13, 30 pcs	7082
Boogie trapezoid adapter, 2pcs	4750
Top plate St. Steel 10 mm	11200
G-10 structure+Miscellanous	600
Total	~35 000
LN2 = 4.6 l	+ 3700
Total weight LN2 filled	~ 39000

*Application of HTS bulks in cryostat, trapping fields including compact cryo-system, mobility, perfect thermal insulation, and coupled with strong mechanical interface for high levitation forces.

Latest technical step
- Top plate exchange G-10 against St. Steel material
- Better insulation vacuum → 10E-5 mbar
- Reduced thermal loss 5→4 W, operation 35 h→>40 h
- On board HTS magnet

Technical ratios:
levitation/weight ratio 600 /39 = 15 :1
levitation/HTS mass ratio 600/7= 85 :1

Cryo distance: 3 mm!
(vacuum insulation+superinsulation)

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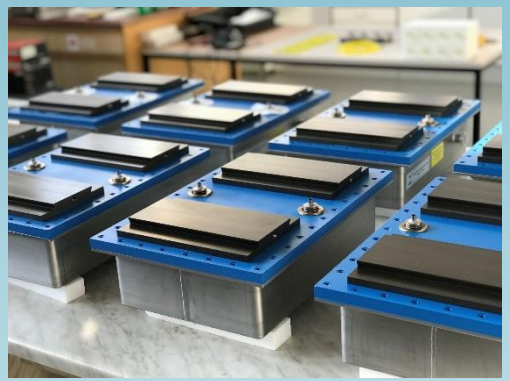
Mobile cryostat/magnet assembling for Maglev



Previous G-10

New St. Steel

YBCO bulk mass production

Strictly application-oriented REBCO bulk fabrication

U. Floegel - Delor et al. 2020 *J. Phys.: Conf. Ser.* **1559** 012046

Load capacity: Cryo250; 0.25 t @ 10 mm
Cryo500; 0.50 t @ 10 mm
0.60 t @ 10 mm, Halbach

Trapped field results YBCO mass production

- 77 K→ B_t =1.5 T (1 mm)
- 40 K→ B_t = 13.35 T mini magnet
- 30 K→ B_t = 16.85 T min magnet
- 25 K→ B_t = 9.78 T ring

O. Vakaliuk et al.
Supercond. Sci. Technol. **33** (2020) 095005 (9p)

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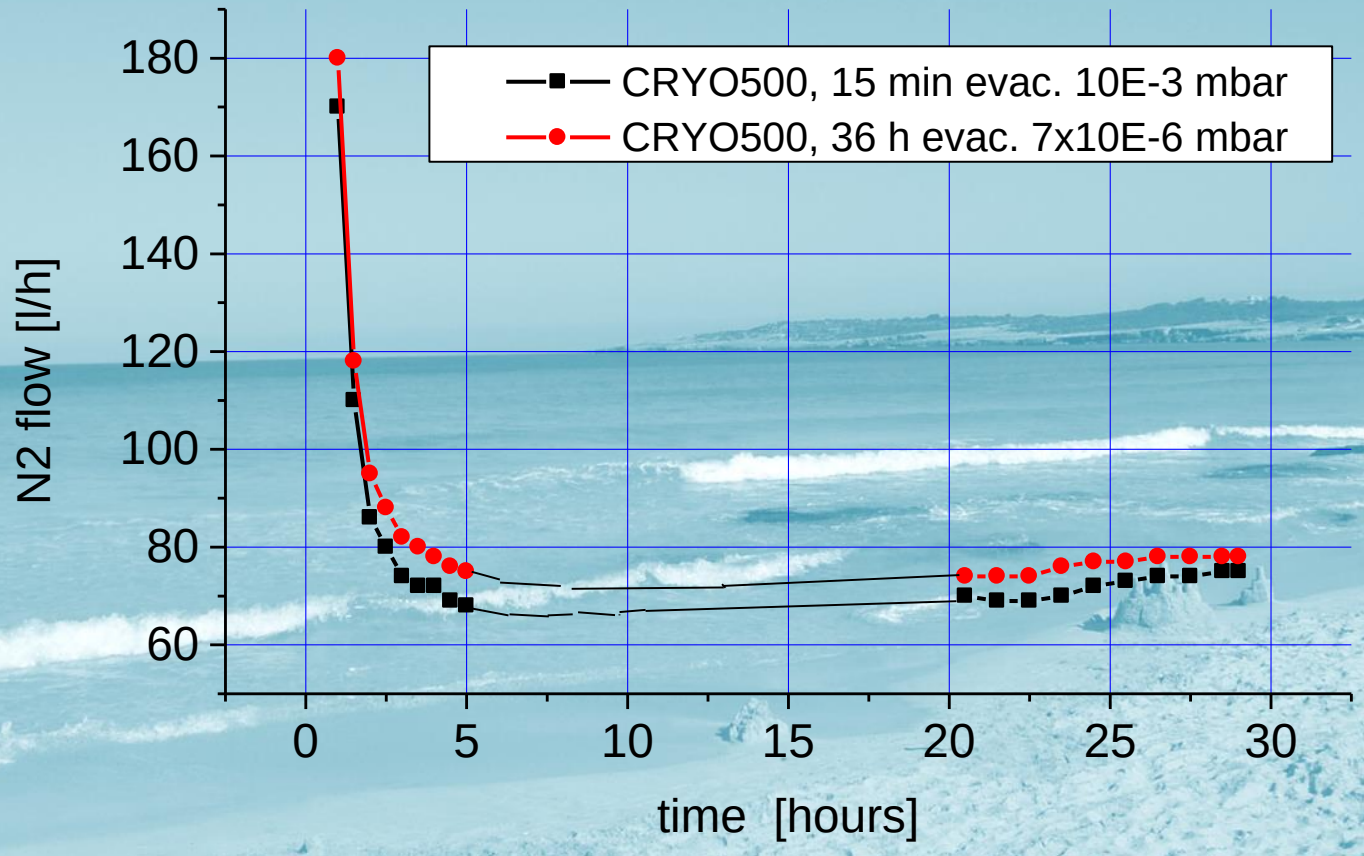
Effect of vacuum insulation



Displacement force relation CRYO250

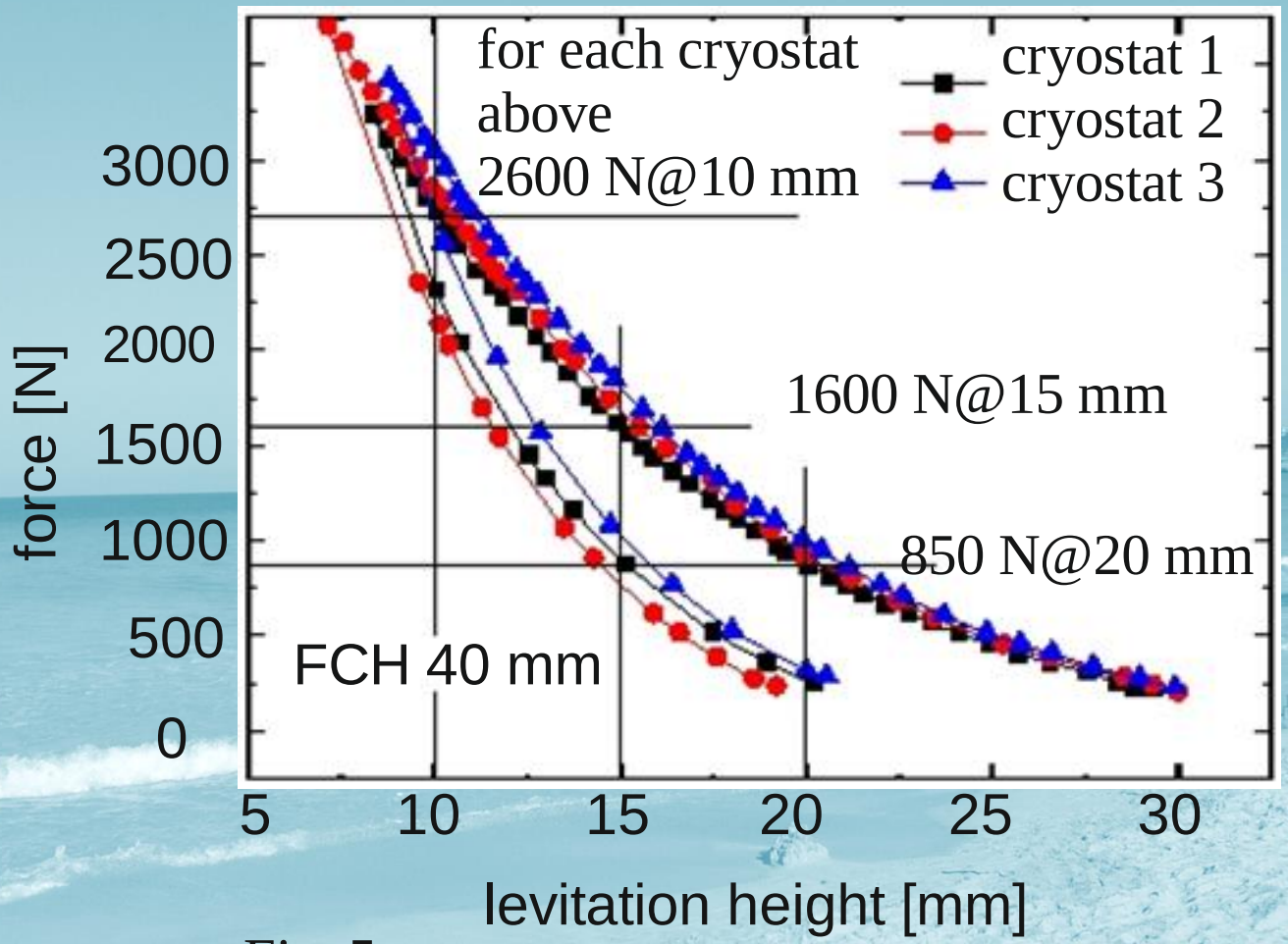


Fig. 5
Total magnetic force dependence on the levitation height [5, 6]

Mobile cryostats: Scaling levitation forces and speed

Scaling	CRYO125	CRYO250	CRYO500
Load@10 mm [kg]	120	250	600
Weight [kg]	14.4	17.2	35
Load / weight	8.3	14.5	17.1
Speed [km/h], test	340	35	20
Ref. / Lit.	Deng et al.	Schultz et al.	Jan. 12, 2021
		Sotelo et al.	Xinhua| 2021

Z. Deng *et al*., "A **High-Speed Running** Test Platform for High-Temperature Superconducting Maglev," in *IEEE Trans. Appl. Supercond.*, vol. 32, no. 4, pp. 1-5, June 2022, Art no. 3600905, doi: 10.1109/TASC.2022.3143474.

L. Schultz et al., "Superconductive levitated transport system - The **SupraTransproject**," IEEE Trans. App. Supercond., vol.15, no. 2, pp. 2301-2305, Jun 2005.

G. G. Sotelo et al., "Tests With One Module of the Brazilian **Maglev- Cobra Vehicle**," IEEE Transactions on Applied Superconductivity, vol. 23, no. 3, Jun 2013, Art no. 3601204.

Xinhua| net 2021-01-16, **Peacook** train

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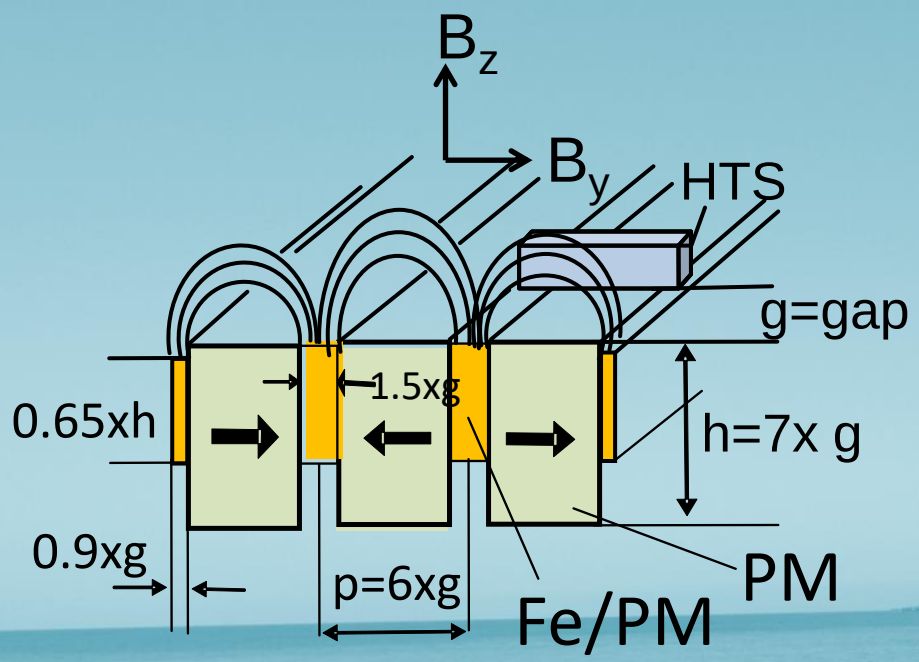
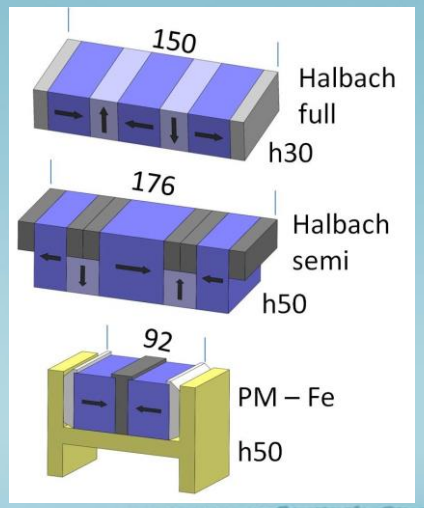
PM guideway configuration



Gap-dependent empirical PM-configuration

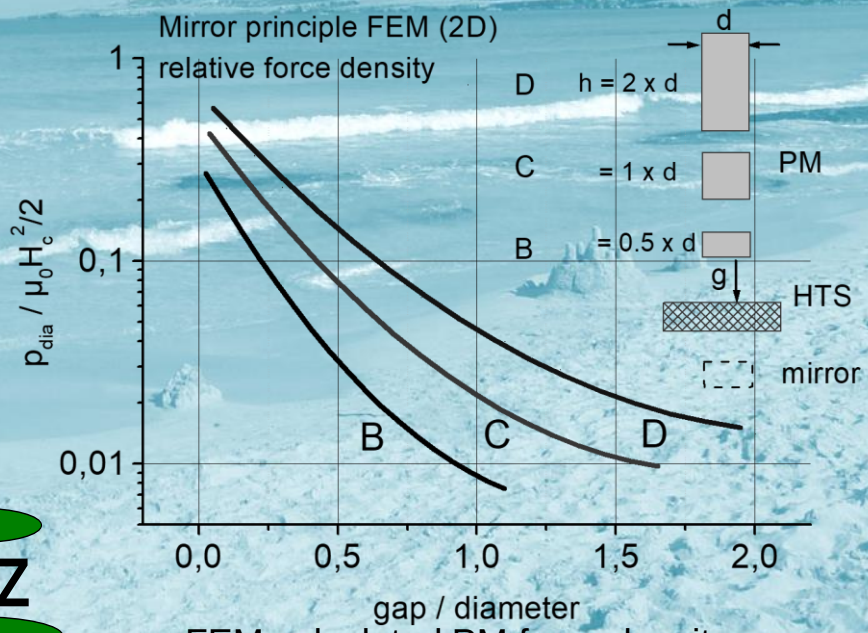
Magnetic field [T]	Force density kN/m²
0.4	63.7 (mirror-like)
0.6	143
1.0	398
2.0	1592
5.0	9950



Cost of PM guideway*

- 50 $ / kg NdFeB
- 1 km→7 tons PMs
- 2x1 km PM→**3.5 m$**
- Comparison:
  1km EU ICE track
  12-30 m$

* Ref. Z. Deng , J. Magn. Magn. Mat. Vol. 420, 2016,171-176



FEM calculated PM force density

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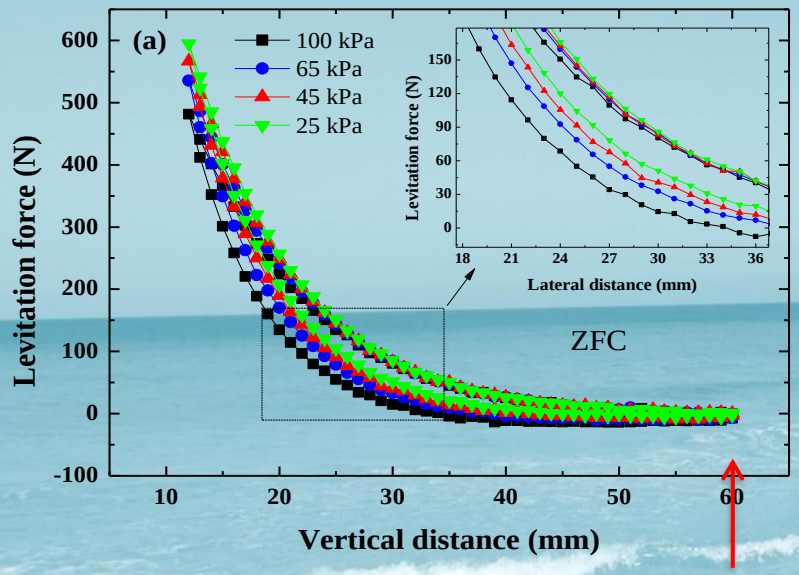
High-Temperature Superconducting Maglev Train

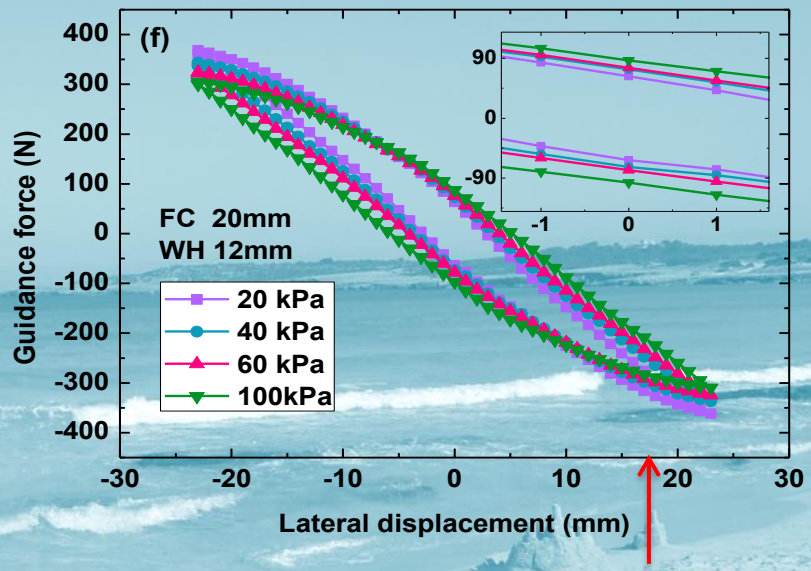
Overall index

- **Test line Length: 165 m**
- **Track gauge: 2 m**
- **Levitation capacity: 15 t**
- **Rated passenger capacity: 30**
- **Levitation height: 10 mm**
- **Expected top speed: 620 km/h**

Jan.13, 2021 the HTS Maglev train prototype was developed in Chengdu, China.

◆Enhancement of the levitation force at low air-pressure ◆environment

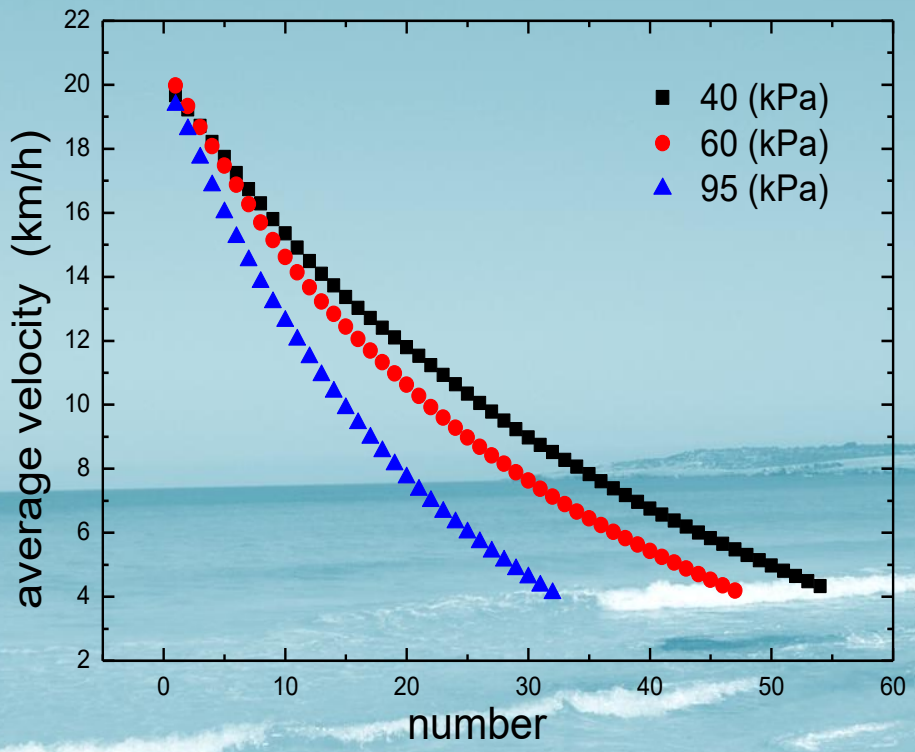




Levitation force **25 %**

Guidance force **30%**

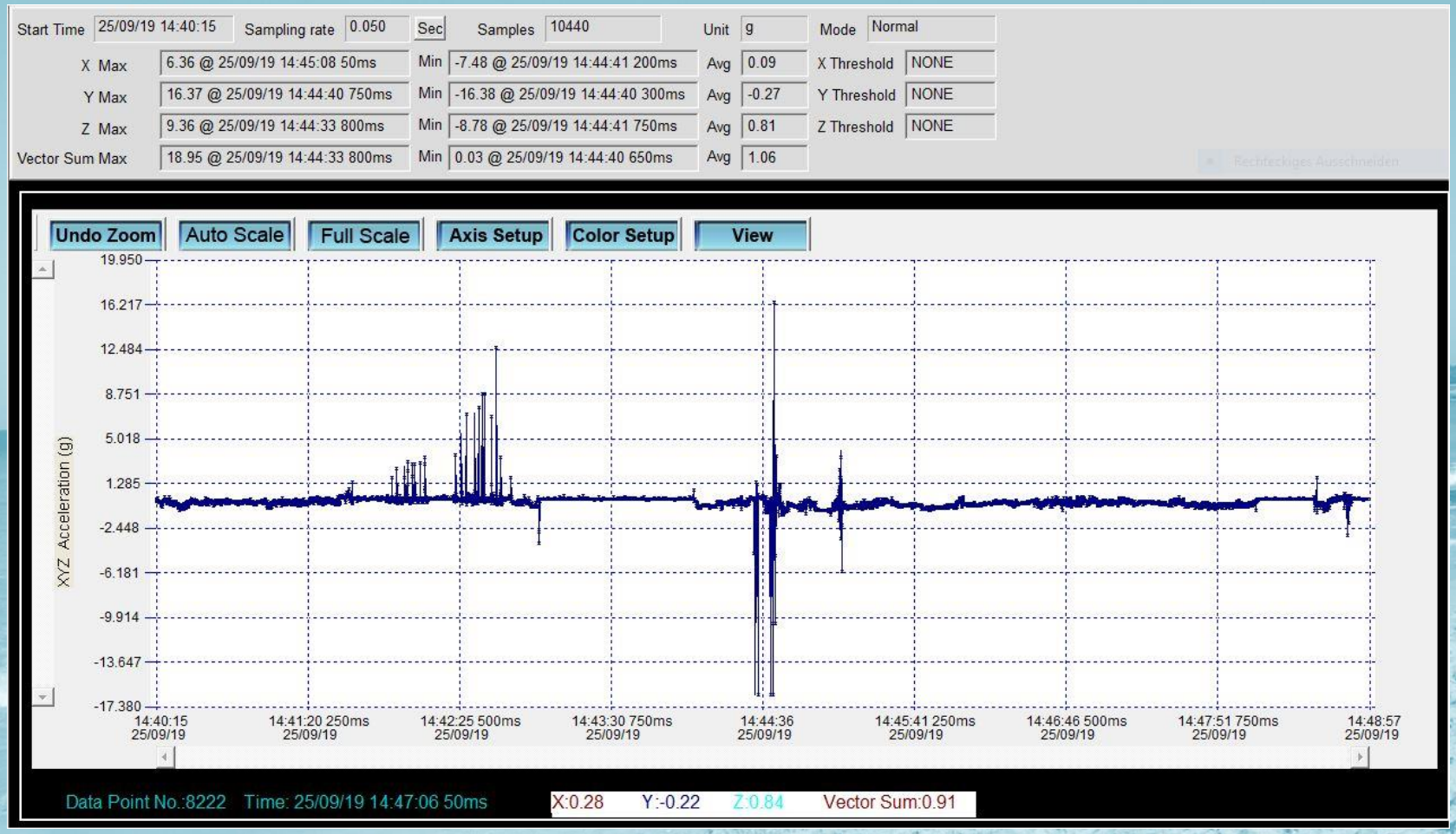
Running Test in low air-pressure



Running resistance: 61% ↓

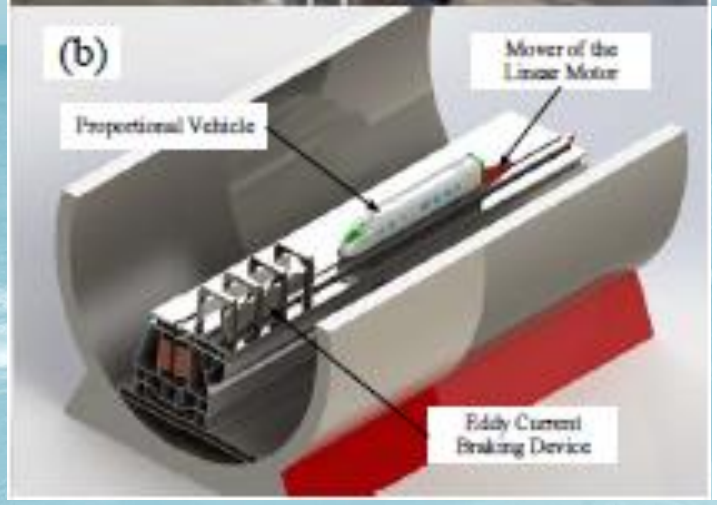
[4] *Z. Deng, et al. , IEEE Trans. Appl. Supercond., Vol. 27, No. 6, 2017.*

Acceleration experiments with CRYO125

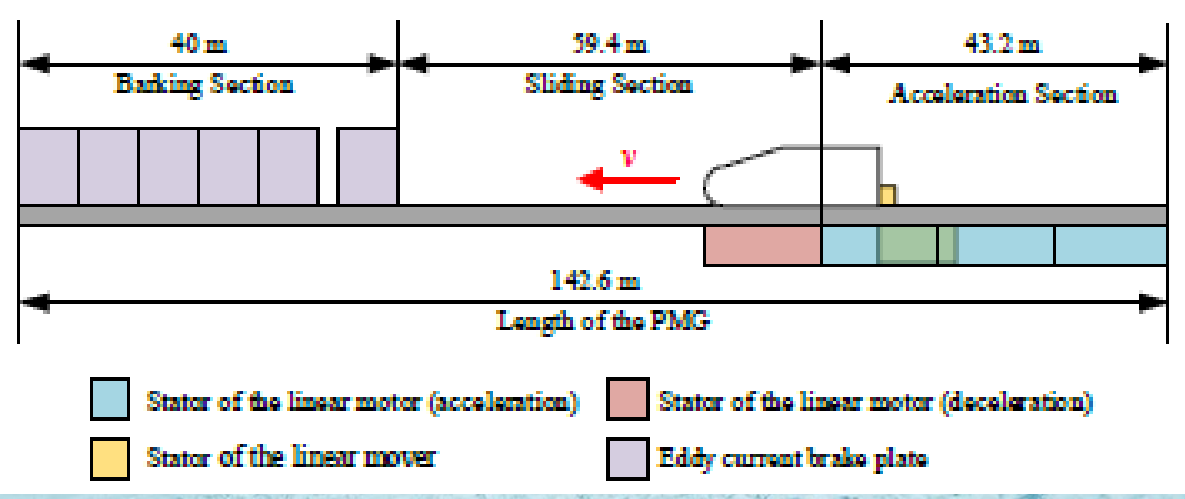


CRYO125 stable at 10 – 20 g!

HTS Maglev High-Speed Test Platform (scaling speed)



Tube Diameter 4.2 m
Tube Length 142.6 m
Model vehicle weight 220 kg
Acceleration 15 g (no cryo-cooler!)
Deceleration (eddy currents) ~30 g
Traction force 70 kN
Linear Motor 16 MW (Storage 28.5 MJ)
Present speed ~340 km/h



Z. Deng *et al*., "A High-Speed Running Test Platform for High-Temperature Superconducting Maglev," in *IEEE Transactions on Applied Superconductivity*, vol. 32, no. 4, pp. 1-5, June 2022,)

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High-Speed Maglev vehicle

Test speed
v~340 km/h

Ref. Z. Deng, SWJTU, Chengdu, China, priv. communication

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4. Conclusion

- Maglev train concepts are considered for Urban + intercity transportation; 50% of the world population lives in cities!
- EMS technology, controllability and reliability are dominant
- EDS is a challenge technique, a few countries only possess ability
- HTS + PMs can generate levitation force densities of 2 tons/m.
- HTS (wires and bulks) will raise magnetic energy B x H further, mobile cryo-technique necessary for future powerful train suspension and propulsion.
- Except ground transportation, Maglev may support future airplan departure and landing, including Earth-to-Orbit-Launch systems.