



Growing Global Interest in Maglev Trains Highlights Next-Generation High-Speed, Frictionless and Sustainable Rail Transportation Technology

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Recent Developments:

- **Magnetic Levitation (Maglev)** technology has regained global attention as several countries explore **ultra-high-speed rail systems** capable of operating at speeds exceeding **400 km/hr** using magnetic fields instead of conventional wheels.
- **Japan's Chuo Shinkansen SCMAGLEV** project has recently moved forward after a major construction approval, although high construction costs and environmental concerns remain significant challenges.
- Commercial **Maglev** operations remain limited primarily to **China, Japan and South Korea**, reflecting the technology's high infrastructure cost and specialised engineering requirements.

Magnetic Levitation (Maglev):

About:

- **Maglev** is derived from the term "**Magnetic Levitation**", in which powerful magnetic fields lift, guide and propel trains without physical contact between the train and the track.
- Since the train remains suspended above the guideway, **rolling friction is eliminated**, enabling smoother operation, lower mechanical wear and significantly higher operating speeds.
- **Maglev** systems are less affected by adverse weather conditions such as rain or snow, provide minimal vibration and can safely operate at speeds exceeding **400 km/hr**.

Scientific Principle:

- The technology is based on the interaction between the **electromagnetic force** and **gravity**, one of the four fundamental forces of nature.
- Since the **electromagnetic force** is enormously stronger than gravity, magnetic fields can lift and control trains weighing **150–500 tonnes** with high precision.

Working Principle of Maglev Trains:

Electromagnetic Suspension (EMS):

- **Electromagnetic Suspension (EMS)** is the most widely adopted **Maglev** technology, in which electromagnets mounted beneath the train attract it towards the guideway.
- The train partially surrounds the guideway using suspension arms, while continuously monitored sensors maintain an operating clearance of nearly **10 mm** above the track.
- Continuous electronic feedback ensures stable levitation throughout operation.

Electrodynamic Suspension (EDS):

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- **Electrodynamic Suspension (EDS)** employs **superconducting magnets** cooled to extremely low temperatures to generate powerful magnetic fields.
- As the train moves, these magnets induce electric currents in coils embedded within the guideway through **electromagnetic induction**, generating a repulsive magnetic force that lifts the train.
- The train normally floats around **100 mm** above the guideway and initially uses auxiliary wheels until reaching nearly **100 km/hr**, after which magnetic levitation becomes effective.
- **Japan's SCMaglev** system using **EDS** achieved a record speed of **603 km/hr** during testing in **2015**, making it the fastest train ever tested.

Propulsion Mechanism:

Linear Motor Technology:

- The guideway contains coils carrying **alternating current (AC)**, producing continuously shifting magnetic poles along the track.
- Magnets mounted on the train are simultaneously **attracted towards the opposite magnetic pole ahead** and **repelled by the similar pole behind**, generating continuous forward motion without physical contact.
- Train speed is increased by raising the **frequency of alternating current**, while braking is achieved by reversing the magnetic field.
- **Regenerative braking** allows braking energy to be returned to the electrical grid, improving overall energy efficiency.

Stability and Safety:

- Side-mounted magnets continuously maintain lateral stability by correcting deviations from the centre of the guideway.
- **Auxiliary wheels, friction brakes and mechanical braking pads** provide backup safety systems during emergencies or magnetic system failures.

Advantages of Maglev Technology:

Transportation Benefits:

- **Maglev** significantly reduces inter-city travel time by operating at ultra-high speeds.
- The absence of wheel-track contact minimises mechanical wear, vibration and maintenance requirements.
- The technology reduces dependence on short-distance air travel and supports low-carbon transportation when powered by renewable electricity.
- Lower mechanical friction also reduces operational noise compared with conventional railway systems.

Technological Significance:

- **Maglev** demonstrates advanced applications of **electromagnetism, superconductivity, automation** and **precision engineering**.
- Continuous research in **superconducting materials** is improving efficiency, reliability and future commercial viability.
- Innovations developed for **Maglev** contribute to advancements across multiple high-technology industries.

Limitations of Maglev Technology:

Infrastructure Constraints:

- **Maglev** requires completely dedicated guideways and cannot operate on conventional railway tracks or existing railway stations.
- Construction demands extremely precise engineering for magnets, coils and guideway alignment.

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- The **Shanghai Maglev**, commissioned in **2004**, required exceptionally high capital investment, excluding land acquisition and long-term operational costs.

Economic Challenges:

- Commercial viability depends upon consistently high passenger demand to recover infrastructure investments.
- High construction, maintenance and operational costs limit large-scale adoption, particularly in developing countries.

Engineering Challenges:

- Speeds beyond **300 km/hr** generate substantial aerodynamic drag and pressure waves.
- Advanced aerodynamic designs, including elongated **bird-beak-shaped noses**, are required to minimise air resistance, tunnel shock waves and noise pollution.
- These engineering requirements further increase project complexity and cost.

Applications Beyond Railway Transport:

Industrial Applications:

- **Maglev** technology supports **high-speed turbines, compressors** and other rotating machinery by replacing conventional bearings with magnetic suspension.
- **Linear motor** systems derived from **Maglev** technology assist aircraft launch systems aboard aircraft carriers.
- Factory automation uses **Maglev** systems for **semiconductor manufacturing, pharmaceutical packaging, food processing, CNC machining, laser inspection** and **DNA sequencing** requiring highly precise motion.

Scientific Research:

- **Maglev** enables contact-free handling of **biological samples, molten metals, liquid droplets** and experimental organisms where vibration-free environments are essential.

Global Status of Maglev Systems:

Operational Systems:

- **Shanghai Maglev (China)** has operated commercially since **2004** with a top operating speed of **431 km/hr**.
- **Linimo (Japan)** operates as a low-speed urban **Maglev** system.
- **Incheon Airport Maglev (South Korea)** serves airport transit operations.
- **SCMAGLEV (Japan)** remains under construction and represents the world's most advanced high-speed **Maglev** project.

Future Outlook:

- Several countries continue evaluating **Maglev** for ultra-high-speed inter-city transportation; however, infrastructure cost remains the principal barrier to widespread adoption.
- Future progress depends upon improvements in **superconducting materials, construction economics** and long-term passenger demand.

Relevance for India:

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Strategic Importance:

- India currently has no operational **Maglev** railway system, although the technology has been discussed for future ultra-high-speed transportation corridors.
- The **Mumbai–Ahmedabad High-Speed Rail** project uses **Shinkansen wheel-on-rail technology**, not **Maglev** technology.
- **Maglev-based automation** could support India's growing **semiconductor manufacturing** and advanced industrial automation ecosystem.
- High infrastructure cost remains the principal constraint for adopting **Maglev** within India's broader transport infrastructure priorities.

Value Addition for UPSC:

Comparison Between High-Speed Rail and Maglev:

- **Conventional High-Speed Rail** uses steel wheels on steel rails, while **Maglev** operates without physical contact using electromagnetic forces.
- **Maglev** generally offers **higher speeds, lower maintenance and smoother operation**, whereas conventional high-speed rail requires lower initial investment and can utilise existing railway infrastructure.

Japan holds the world speed record for a train at **603 km/hr** using **SCMAGLEV**, while **China** operates the world's fastest commercial **Maglev** service at **431 km/hr**