MAGLEV

Quest explores the use of magnetic levitation in cutting-edge transportation systems

The fastest commercially operating train in the world relies on magnetism to travel at up to 431 km/h, but this record 'rail' speed could almost triple if ambitious plans for hyperloop systems come to fruition.

Maglev trains

China's Shanghai Maglev Train provides a shuttle service between the Pudong International Airport and a station on the outskirts of the vast Shanghai Metro system of interconnecting lines, doing the 30 km trip in about eight minutes. It used to have a morning and afternoon slot to show off its maximum commercial speed of 431 km/h, but currently sticks to a more sedate 300 km/h for the duration of its daily operating hours.

Maglev is short for magnetic levitation, a technology that allows trains to rise, or levitate, above the track and be propelled along by magnetic forces. Without the friction of rail-wheel contact or the need to carry heavy engines and braking systems, maglev trains require less maintenance, offer a smooth ride, and can reach tremendous speeds. The world record for conventional high-speed rail was set at 574.8 km/h by a TGV electric train in France in 2007, but in normal operation the TGV trains travel at a top speed of 320 km/h. A maglev Series LO train developed for the Central Japan Railway Company – known as JR Central – was clocked at 603 km/h during a test run on the experimental Yamanashi Maglev Line in 2015, a feat recognised as a Guinness World Record.

There are plans to extend the 43 km experimental line in both directions to form the Chuo Shinkansen maglev line between Tokyo and Osaka. An initial 286 km section between Tokyo and Nagoya was scheduled to open in 2027, but delays caused by the pandemic as well as environmental concerns about tunnel construction mean

The Shanghai Maglev Train in China is the world's fastest train in operational service, with a maximum commercial speed of 431 km/h.

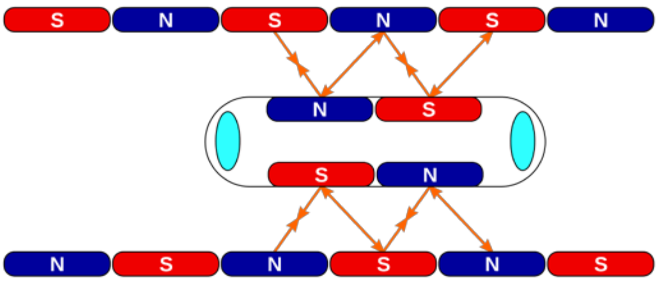
that this will not be possible. In normal operation the trains will travel at a maximum speed of 500 km/h, and this – together with the more direct, mostly underground route – would shorten the train journey from two hours to just 40 minutes.

The system uses the Japanese-designed SCMaglev technology, which relies on superconducting magnets installed on the sides of the train and two types of electromagnetic coils on the sides of the U-shaped track, called the guideway. The attraction and repulsion forces created by the interaction of these magnets levitate the train by 10 cm, keep it aligned in the centre of the guideway, and propel it forward. Adjusting the frequency of the alternating current supply to the propulsion coils – in other words, the rate at which the current changes direction per second – changes the rate of polarity switching between north and south, allowing control over the train's speed. This is an electrodynamic suspension system, requiring the train to have wheels that only retract once a certain speed is reached and the current induced in the coils creates a magnetic force strong enough to achieve levitation.

The superconducting magnets are essentially electro-magnets made from coils of niobium-titanium wire. To become superconducting – a state where there is no electrical resistance – the wires must be cooled during operation to −269°C. Without the problem of resistance-induced heating, the wire can conduct much larger electric currents than ordinary wire, allowing the creation of intense magnetic fields. Liquid helium is used to achieve this cryogenic temperature within a circulation system that incorporates liquid nitrogen for cooling too.

A Series LO train using SCMaglev technology reached a record-breaking speed of 603 km/h on the experimental Yamanashi Maglev Line in Japan in April 2015.

Research is being conducted on so-called high-temperature superconductors made from materials that do not require



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In magnetism, opposites poles attract and like poles repel. In the SCMaglev system, superconducting magnets on the sides of the train interact with electromagnetic coils on the guideway walls to pull and push the train along, creating propulsion.

Andreas Heddergott, TUM

Teams from the Technical University of Munich have won each of the four hyperloop pod racer competitions held to date. This 2019 prototype, TUM Hyperloop Pod Four, holds the competition record at 482 km/h.

cooling with liquid helium. In January 2021, China unveiled a prototype of a high-temperature superconducting maglev train and claimed that it would be able to reach 620 km/h. This is only a design speed based on modelling by the technology's developers – a research team from Southwest Jiaotong University – as the track built for the prototype is just 165 m long.

By contrast, the Japanese SCMaglev system is proven technology, and is being considered for adoption elsewhere. In the United States, an environmental impact assessment process is under way for a high-speed SCMaglev route between Washington, DC and Baltimore, Maryland, and in Australia it has been promoted for a route linking Sydney, Canberra and Melbourne.

Nevertheless, since there are no SCMaglev systems in commercial operation at this stage, the Shanghai Maglev Train in China, which has been in commercial operation since 2004, is still the fastest 'running' train in the world. It uses the Transrapid electromagnetic suspension system developed in Germany by Siemens and ThyssenKrupp, relying on attractive forces between the track and ordinary electromagnets on the wrap-around bottom of the train.

This was not the first maglev system to be implemented – the technology was invented in the 1960s and a number of smaller and much slower versions have either been discontinued or are still in operation. The very first such service was in England, where a shuttle with a top speed of 42 km/h covered the 600 m between Birmingham International Airport and the nearby railway station from 1984 to 1995. Today, a similar service known as the Ecobee is operated on a 6 km route at Incheon Airport in South Korea, and in Japan the Linimo, built for Aichi Expo 2005, covers a 9 km route near Nagoya. Both are driverless systems with maximum speeds of around 100 km/h.

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The Ecobee is operated on a 6 km route at Incheon Airport in South Korea.

Hyperloop

Hyperloop could take maglev to a new level. The term was coined by Elon Musk in 2012 and he elaborated on the concept the following year in a 'white paper' written with assistance from engineers at SpaceX and Tesla Motors. He noted that while the idea of travelling in either a pneumatic tube with air-propulsion or a vacuum tube with electromagnetic suspension was not new, neither were practical. He proposed instead a low-pressure (partially evacuated) tube system to minimise aerodynamic drag, with pods levitated on a cushion of compressed air and propelled by a magnetic linear accelerator at various stations along the tube. The pods would travel at up to 1 220 km/h, allowing a 35-minute trip between Los Angeles and San Francisco in California on a preliminary route mapped on Google Earth.

Musk 'open sourced' the hyperloop concept and encouraged others to contribute to the design process to help bring the idea to a reality. In January 2015, he tweeted that he would be building a hyperloop test track and was thinking of running an annual hyperloop pod racer competition for students. The competition, hosted by SpaceX, was subsequently announced in June 2015 and began with a design phase. Suspension could be via wheels, air bearings or magnetic levitation. About 120 designs from teams around the world were judged in January 2016 and 30 teams were selected to build prototype pods. Construction of the 1.6 km test track, called the Hypertube, was only completed in October 2016, so the first year's entries were put to the test in January 2017, with subsequent on-track competitions later that year and in 2018 and 2019. Musk announced plans to build a longer, 10 km track for the 2020 competition, but this was called off because of the pandemic.

The first four competitions were all won by a team from the Technical University of Munich (TUM) in Germany. Their initial pod prototype reached a top speed of 94 km/h in the first competition, but by the 2019 competition this had increased to 482 km/h, using a much smaller pod weighing only 69 kg. The TUM Hyperloop team is currently building a full-scale demonstrator consisting of a 24 m-long tube and a human-sized passenger pod.

Some of the other student teams have also formed companies to continue working on hyperloop, and a few start-ups were initiated soon after Musk released his white paper. Some have folded or gone quiet, but two have made significant advances. The most high-profile, perhaps, is what started out as Hyperloop Technologies and then became Hyperloop One and then Virgin Hyperloop One – after Richard Branson invested in the company and joined the board of directors in October 2017 – and then just Virgin Hyperloop from June 2020. It completed construction of a 500 m low-pressure test track, called DevLoop, in the Nevada Desert outside Las Vegas in 2017 and has done more than 500 tests since then. The highest speed achieved with the full-scale pod to date is 387 km/h, but this is on only 500 m of track; Virgin Hyperloop estimates that a fully developed system will transport cargo or passengers at 1 080 km/h. In November 2020 the first test with human passengers was conducted in a two-seater pod, and this was done at a top speed of 172 km/h, but Virgin Hyperloop envisages a system with 28-seater pods departing a station together, travelling in convoy and splitting off to different destinations. A concept video released in August 2021 describes battery-powered pods gliding smoothly and safely using Virgin Hyperloop's "proprietary magnetic levitation and propulsion".

The other major player is Hyperloop Transportation Technologies (HyperloopTT), which was started in the United States with crowdfunding in October 2013 but now has offices in North and South America, the Middle East and Europe. Rather than hiring employees, HyperloopTT set up a network of expert contributors who work in exchange for shares in the company. Currently there are more than 800 of such contributors and 50 full-time employees, interacting in 52 multidisciplinary teams with corporate and university partners. The company unveiled a passenger pod in 2018, completed construction of a 320 m test track at its R&D Centre in Toulouse, France, in early 2019 and began running tests a few months later. Its proprietary maglev technology is based on the Inductrack system developed at the US Lawrence Livermore National Laboratory in the 1990s and optimised for a low-pressure environment by HyperloopTT. It uses arrays of permanent magnets – called Halbach arrays – on the pod, and is a passive system that does not require electromagnets or superconducting coils to achieve levitation over an unpowered but conductive track. HyperloopTT believes its fully developed system with pods seating 28 to 50 passengers will be capable of reaching speeds of 1 223 km/h.

Neither Virgin Hyperloop nor HyperloopTT are exploring Musk's proposed Los Angeles to San Francisco route, but both are in negotiations or have signed agreements with

Virgin Hyperloop

Virgin Hyperloop

Virgin Hyperloop's two-seater XP-2 (Experimental-Pod-2) is prepared for loading into the DevLoop tube for the world's first passenger hyperloop test in November 2020. Larger pods seating 28 passengers and travelling in convoy are envisaged for full-scale implementation.

various companies, regional partners and governments in the United States and other countries, and feasibility studies for different routes have been completed or are under way. Both also made presentations to the US Congress subcommittee dealing with railroads in May 2021, as part of a hearing on 'The benefits and challenges of high-speed rail and emerging rail technologies'. In August the US Senate passed the Infrastructure Investment and Jobs Act, which mentions hyperloop technologies. If the legislation is passed by the House and signed by President Biden, US-based hyperloop projects would be eligible for government loans and grants.

Déjà vu

Maglev projects have already been eligible for such funding for some time. In June 1998, the Maglev Deployment Programme for high-speed transportation was authorised by the US Congress in the Transportation Equity Act for the 21st Century, and the first round of applications for funding closed in February 1999. The Department of Transportation's Federal Railroad Administration ultimately selected two projects – in Maryland and Pennsylvania – for additional studies including engineering design and site-specific environmental assessment, with the aim that one of these would be given capital assistance for construction, subject to the appropriation of funds by Congress.

The Maryland one was a 64 km route from Baltimore to Washington, DC, with a stop at the Baltimore/Washington International Airport, and was going to use the German

Hyperloop TT

The HyperloopTT pod, or capsule, is designed to seat 28 to 50 passengers.

Hyperloop TT

HyperloopTT's test track at its R&D Centre in Toulouse, France, is 320 m long.

Transrapid maglev technology. In 2003 Maryland halted the project, but when the Federal Railroad Administration issued a call in 2015 for funding applications under a new Maglev Deployment Grants Programme, the concept was revived by a private entity, Baltimore-Washington Rapid Rail, this time relying on SCMaglev, as previously mentioned. The Grant Programme has awarded funding for only one project in each of the three funding rounds in 2015, 2019 and 2020, and in every case it was the Baltimore-Washington SCMaglev Project that was successful, with grants totalling US$53.8 million.

Meanwhile, Elon Musk has apparently abandoned his plan to dig a tunnel covering the same route. In July 2017 he tweeted that he had received verbal approval to build a hyperloop tunnel connecting New York, Philadelphia, Baltimore and Washington, DC. In October of that year the Maryland state government confirmed that it had issued a conditional permit to Musk's The Boring Company to begin digging a 16.5 km tunnel on its land beneath the Baltimore-Washington Parkway, the 56 km-long highway between the two cities. By April 2019 a draft environmental assessment had been completed for The Boring Company's so-called Washington DC to Baltimore Loop Project, the concept having been changed to parallel, twin tunnels through which passengers would be transported in autonomous, battery-powered electric vehicles at speeds of up to 240 km/h. The underground tunnels would potentially serve as corridors for hyperloop pods travelling at 1 120 km/h in the future. Two years later, in April 2021, news media reported that the project had been removed from The Boring Company's website, and appeared to be 'dead'.

It's highly likely that if a hyperloop system is eventually implemented anywhere, the first one is not going to be in the United States, given the existing transport systems, land-use rights, funding constraints and more pressing socio-economic priorities. Although considered an environmentally friendly technology because of its lack of direct CO_2 emissions, the elevated tubes would have high visual impact. Its proponents say hyperloop will be safer than road, rail and air travel because it will not be affected by adverse weather conditions and, in the case of road travel, high rates of human error and reckless driving, but there are concerns about sabotage and earthquakes, not to mention the inherent risks of travelling at such great speeds. Implementing it for freight alone is not feasible, owing to its high construction cost and ongoing energy demands, which could be at least partly offset by covering both the tubes and stations in photovoltaic technology for solar power. In January 2021, the US Department of Energy released a report on its analysis of the 'Effect of hyperloop technologies on electric grid and transportation energy', which showed that hyperloop transport of freight would be less energy-efficient than all other modes of freight transport except for air.

High-speed maglev trains, too, are prohibitively expensive to build, have high energy demands, are quite noisy due to air displacement, and are impractical to implement, given the difficulty of integrating them with existing railway networks. To be financially feasible, they'd need enough passengers travelling between cities and able to pay the high ticket price, but preferring to take a train rather than a plane.

Low- to medium-speed maglev trains within cities are suggested by some analysts to be more promising, having the benefits over existing urban transport systems of no emissions and low noise. Back in 1999, the US Federal Transit Administration initiated the Low-Speed Urban Magnetic Levitation Programme and funded five projects to develop such systems. A 'lessons learned' report evaluating the programme was published a decade later, and by that time only two of the project teams were still working on maglev. Although a few short test tracks were built by these or other projects, no maglev train system has been implemented in the US to date – a fact that brings about a 'déjà vu' feeling that we've been here before.

For a better understanding of the technology, JR-Central has an interactive animation explaining the SCMaglev system: https://scmaglev.jr-central-global.com

HyperloopTT have a set of diagrams depicting the principles of the Inductrack-Halbach array technology at the bottom of this webpage: https://www.hyperlooptt.com/technology/

Virgin Hyperloop released a short video explaining their concept in August 2021. Search YouTube for 'Virgin Hyperloop Explained': https://youtu.be/6hXNXL9PiYk

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