Development of Superconducting Maglev in Japan

By Okumura Fuminao

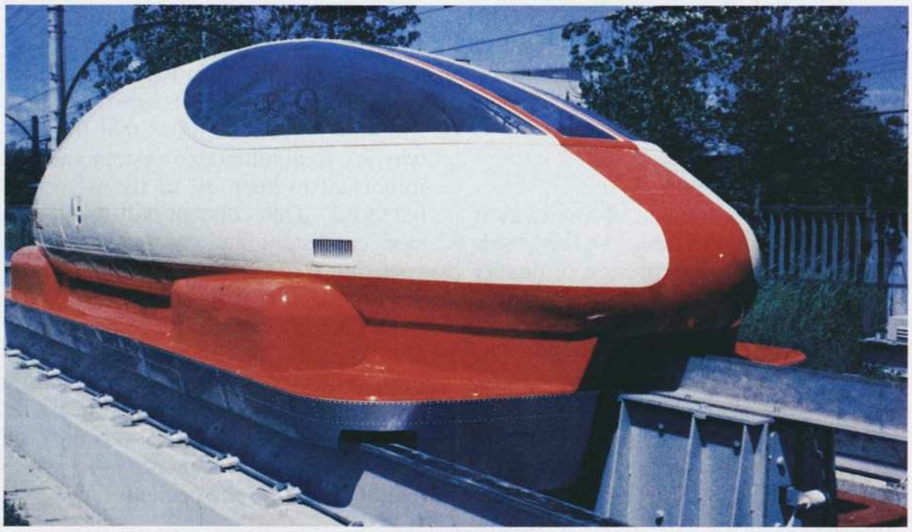

Photo 1: The magnetically levitated model (ML-100) was demonstrated in October 1972

1. Introduction

Research and development of the superconducting magnetically levitated linear motor car (Maglev) have been continuing for a quarter of a century. Maglev has been developed as a super high-speed railway worthy of the 21st century harmonizing safety with the environment and capable of providing comfortable travel at speeds of 500km/h. The Ministry of Transport (MOT; now known as the Ministry of Land, Infrastructure and Transport) selected an appropriate location for a new experimental line in 1989 in order to proceed with actual practical application and began construction of the Yamanashi Maglev Test Line in 1990. In December 1997, the train reached a speed of 531km/h, a new world record for manned railway operation, eventually reaching a speed of 550km/h, the fastest ever for unmanned operation. In 1999, vehicle running tests were conducted using a five-car train and, on April 14, a new world record of 552km/h was set again for manned operation. An extended five-year plan is under way for reliability and endurance verification tests at the Yamanashi Maglev Test Line.

2. History of Railways in Japan

The railway systems have been well developed in Japan as transportation for the public, especially the *shinkansen* bullet train. The first railway from Shimbashi to Yokohama began operating in 1872. The operation of the Tokaido Line from Tokyo to Osaka was started in 1891. The Tokaido Shinkansen was inaugurated in 1964 and dramatically shortened the travel time between the two cities. The shinkansen system has expanded with more than 2,300km of tracks connecting cities with high speeds of up to 300km/h.

As the Japanese economy grows, the demand for high-speed transport increases. Demand for speed is also increasing with productivity growth and wage raises. Speedup between Tokyo and Osaka has been realized gradually during the past 100 years. Now the shinkansen train Nozomi takes about 2 hours and 30 minutes from Tokyo to Osaka, with a passenger occupancy level of more than 85%. But drastic speedup break-through overcoming the limitations of conventional railway systems has been long awaited.

3. JR Maglev Development

The examination of the development of a new system of super-high-speed railways was begun two years before the 1964 inauguration of the Tokaido Shinkansen. Before the completion of the connection of Tokyo and Osaka by three hours of travel time, the engineers and researchers of the former Japanese National Railways (JNR) began to set a new goal of a one-hour travel time between the two cities. A one-hour travel time by train is much faster than that of airplane. Connecting Tokyo and Osaka by one hour requires a speed of 500km/h. The revenue service speed of 500km/h is impossible by a conventional railway utilizing adhesion between the wheels and rails. A super-high-speed transport system with a non-adhesive drive mechanism, which is independent of wheel-and-rail frictional forces, was needed. The magnetically levitated transport system (JR Maglev), a combination of superconducting magnets and linear motor technology, realizes super-high-speed running, safety, low environmental impact, and minimum maintenance.

JR Maglev is a system in which the vehicle runs levitated from the guideway (corresponding to the rail tracks of conventional railways) by using electromagnetic forces between superconducting magnets on board the vehicle and coils on the ground. The following is a general explanation of the principle of Maglev.

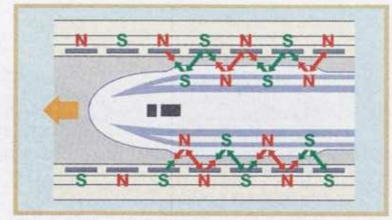

Figure 1: Principle of propulsion

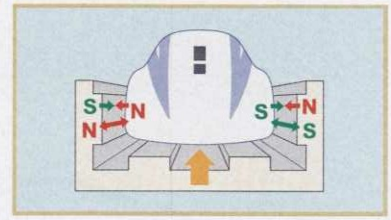

Figure 2: Principle of magnetic levitation

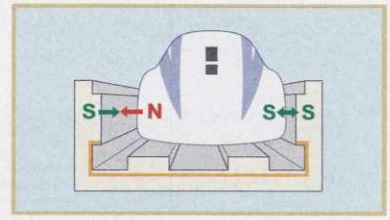

Figure 3: Principle of lateral guidance

Principle of propulsion: A repulsive force and an attractive force induced between the magnets are used to propel the vehicle (superconducting magnet). The propulsion coils located on the sidewalls on both sides of the guideway are energized by a three-phase alternating current from a substation, creating a shifting magnetic field on the guideway. The on-board superconducting magnets are repelled and attracted by the shifting field, propelling the Maglev vehicle. (Figure 1)

Principle of magnetic levitation: The figure "8" shaped levitation coils are installed on the sidewalls of the guideway. When the on-board superconducting magnets pass at a high speed about several centimeters below the center of these coils, an electric current is induced within the coils, which then act as electromagnets temporarily. As a result, there are forces, which push the superconducting magnet upwards, and ones, which pull them upwards simultaneously, thereby levitating the Maglev vehicle. (Figure 2)

Principle of lateral guidance: The levitation coils facing each other are connected under the guideway, constituting a loop. When a running Maglev vehicle, namely the on-board superconducting magnet, displaces laterally, an electric current is induced in the loop, resulting in a repulsive force acting on the levitation coils of the side near the car and an attractive force acting on the levitation coils of the side farther apart from the car. Thus, the running car is always located at the center of the guideway. (Figure 3)

The significance of the development of JR Maglev is discussed from many viewpoints. The first point is the super high speed of JR Maglev. Theoretically, there are no limitations to increasing its revenue service speed. But energy efficiency and investment in facilities result in the speed of 500km/h. JR Maglev is free from the limitations of adhesion of rail and wheel, and also from gradient resistance. The overall speed between the two cities is substantially high compared with that of airplanes, within a certain distance. The second point is the ability of mass transport. The target transport capacity of JR Maglev is 10,000 people per hour one way. This capacity is sufficient for passengers traveling direct from Tokyo to Osaka.

The research and development of Maglev adopting superconducting technology has been under way at the Railway Technical Research Institute (RTRI) in Kunitachi from 1962. After fundamental laboratory tests to verify the feasibility of high-speed running, the test runs of the experimental vehicle ML-100 with on-board superconductive magnets was opened to the public at the RTRI Kunitachi Institute in October 1972, which was also the railway centennial in Japan. (Photo 1)

Photo 2: The ML-500 model set a record of 517km/h in 1979

After this demonstration, the construction of a 7-km test track began in Miyazaki Prefecture in 1975. Test runs of the ML-500 on the inverted-T-shaped guideway started in 1977. The unmanned ML-500 attained a speed record of 517km/h in 1979. (Photo 2) The guideway was then modified to the U-shaped guideway. Experiments using MLU001 started in 1980. Government subsidies for Maglev development were introduced from the time these experiments started. The manned two-car vehicle MLU001 registered a speed of 400.8km/h in 1987. Following the privatization and division of the JNR, the test vehicle MLU002N debuted in 1993. MLU002N achieved a speed record of 431km/h on the Miyazaki Maglev Test Track in 1994, and a manned-test-run record of 411km/h in January of 1995.

4. The Yamanashi Maglev Test Line

In overcoming the limitations of the facilities at the Miyazaki Test Track, a new Maglev test line was awaited. An ad-hoc committee within the MOT for the development of Maglev systems decided on Yamanashi Prefecture as the best candidate for the new test line. In 1990, MOT authorized the construction of a Yamanashi Maglev Test Line as a national project, and officially

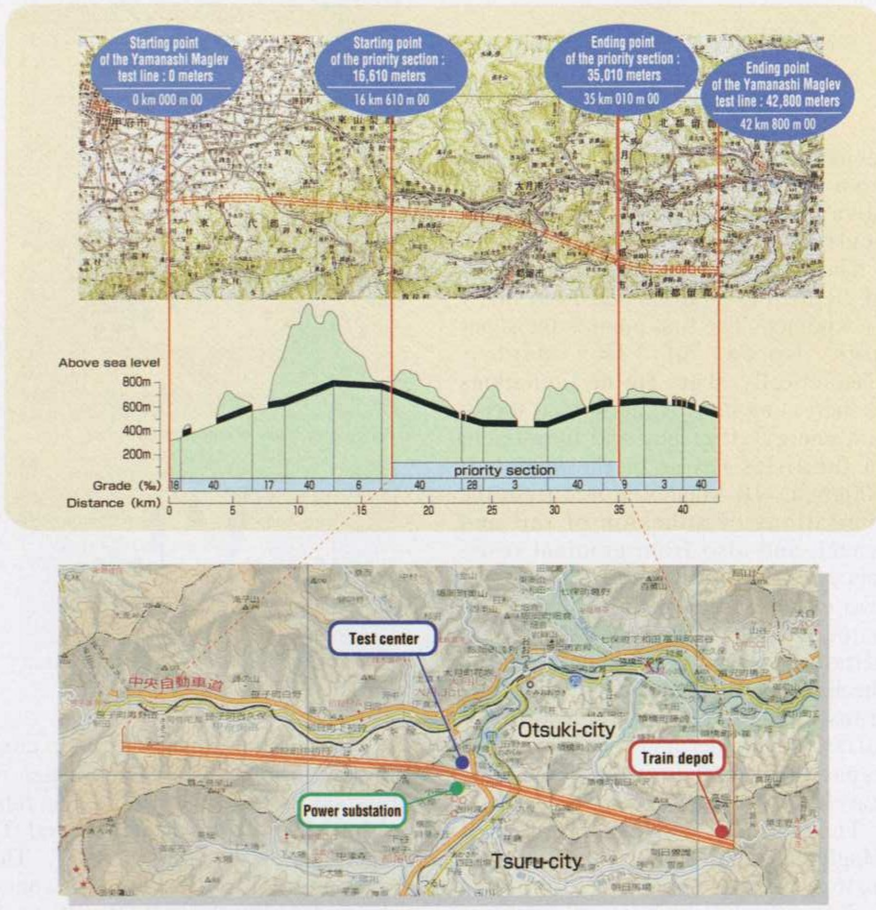

Figure 4: Location of the Yamanashi Maglev Test Line

nominated RTRI, Central Japan Railway Company (JR Tokai), and the Japan Railway Construction Public Corporation (JRCC) as the three bodies responsible for the execution of the project. This nomination established that the feasibility of Maglev operation would depend on the results of experiments on this line. The Yamanashi Maglev Test Line is located about 100km west of Tokyo. It has a total length of 42.8km with a minimum curve radius of 8,000m, a maximum gradient of 40/1000 and a minimum distance of 5.8m between the centers of the two tracks of the guideway. Eighty percent of the line runs through tunnels. In the so-called sunlit sections, a girder type viaduct is used as the standard and, at the location of the intersection with the Central Expressway Fuji-Yoshida line, a Nielsen-Lohse type steel bridge was used for the first time as a railway bridge. (Figure 4)

Due to the difficulty that was experienced in acquiring the land, a "priority section" was set up in the vicinity of Tsuru City in July 1992, and tests are currently being conducted on this 18.4km "priority section." A certain section of the test line, 12.8km long, is a double track where it is possible to study the dynamics of trains passing each other at a relative speed of about 1,000km/h. In the summer of 1995, a three-car train set was delivered, and in autumn the substations began to be supplied with electricity.

The purpose of the tests on the Yamanashi Maglev Test Line is to verify the capacity to operate safely and stably at speeds in excess of the target commercial speed of 500km/h. That entails, in other words, verifying that the system has sufficient transport capabilities to respond to the transportation needs between major urban centers that is assumed for the 21st century and can be operated punctually, while holding down construction costs to the minimum and setting up targets that can be realized as a practical system.

Vehicle running tests were started on the Yamanashi Test Line in the spring of 1997. Since the commencement of testing, car running tests, levitated running tests and a speed-up test have been conducted. These involve the verification of car operation safety at each speed range, brake performance, running speed controllability, electrical power converter controllability and so forth while gradually increasing speed. Subsequent to that, maximum speed verification tests were conducted and, on December 24, the target maximum speed of 550km/h was attained within a mere nine months after initiating the tests. About 20 years was needed to break the record of the ML-500.

In 1998, a comprehensive function verification test was conducted. It consists of tests verifying the performance of each function in constant speed tests in various speed ranges up to a speed of 500km/h and substation passage tests when passing feeder boundaries between two control section at a speed of 500km/h. In addition, using two trains of three cars each, a test of two trains passing each other at a relative speed of 966km/h was conducted.

The Superconducting Magnetically Levitated Transportation System Practical Technology Evaluation Committee (Maglev Committee), set up by the MOT in January 1997, is evaluating the results of the tests conducted at the test line. An interim report was prepared at the fifth meeting of the committee held in July 1998, and evaluations of the transportation system and of each subsystem were conducted and no basic problems were observed that would hamper practical application.

From the beginning of 1999, vehicle running tests were continued with recombination to five-car trains. Manned running tests were conducted and a new world railway speed record of 552km/h was set on April 14. Since the intermediate three cars were to be in a loaded condition for this operation, a weight of about ten tons (equivalent to about 140 passengers) was loaded on the cars as well as thirteen passengers who were on board to test riding comfort. The passengers including the author were favored with clear weather that day with an excellent view of the snow-covered peak of Mt. Fuji from inside the cars and the operation proceeded smoothly and safely. In the autumn, tests of two trains passing each other were conducted again and the relative speed reached 1003km/h. (Photo 3)

Figure 5: The orange zone shows the planned line of the Chuo Shinkansen and the blue line indicates the Tokaido Shinkansen

Upon evaluating these test results, the Maglev Committee meeting, held on March 9th 2000, submitted a technology evaluation report of the JR Maglev. They concluded that the JR Maglev is technologically feasible for commercial use, but there was a needs for a five-year extension of the test program for the sake of cost reduction, reliability verification and aerodynamic characteristics improvement.

5. Chuo Shinkansen Project

The ridership of the Tokaido Shinkansen has grown steadily and the number of passengers per day has increased to 360,000. It is foreseen that its transportation capacity will not be able to cope with the demands of the 21st century. Future gains in productivity will create a need for higher transportation speeds. There is a need for futuristic transportation between the two big cities. In Japan, there is a possibility of earthquakes. From a geological point of view, a new line from Tokyo to Osaka should be built on different site from that of the Tokaido Shinkansen. Safety during earthquakes is one of the most attractive points of the JR Maglev. Even though major earthquakes like the Hanshin-Awaji earthquake are quite rare, the safety of this super-high speed transportation system should be assured during and after earthquakes. The gaps between the vehicles and the sidewalls and guideway surface are about 10cm. These vehicles, supported by magnetic springs, should be safe against earthquakes. There should be a redundancy of shinkansen lines between the two big cities because of the natural disasters.

For these reasons, the second connection between Tokyo and Osaka passing directly through mountainous areas has been planned as the Chuo Shinkansen project. In Figure 5, the orange zone shows the planned line of the Chuo Shinkansen and the blue line indicates the Tokaido Shinkansen. The Chuo Shinkansen is one of the basic plans for the shinkansen lines designated by the MOT. The MOT ordered JR Tokai and the JRCC to investigate geographical and geological conditions of the route for the Chuo Shinkansen in 1990. The Chuo Shinkansen is one of the most promising implementation lines for the JR Maglev.

6. Conclusion

Surface transport systems are gradually and cautiously treading the steps toward higher-speed service while confirming total safety and environmental stability. JR Maglev system is one of the most promising candidates for future high-speed transportation. JR Maglev proved the capability of the speed of 550km/h, punctuality, and transportation capacity. It is genuine national technology. The effects of this technological development should be recognized from various aspects. The development of the Maglev system entered a new phase at the Yamanashi Maglev Test Line. In the year 2005, the Maglev committee of the MLIT will evaluate the realization of the JR Maglev. The implementation plan of the JR Maglev for the Chuo Shinkansen has a bright future.

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Photo 3: To test safety and stability, two trains were operated in parallel lanes at a relative speed of 1003km/h

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