1. INTRODUCTION

High Speed is the eternal subject pursued by the mankind in the transportation field. An important achievement of electrical technology for 20th century is the appearance of high-speed Maglev system which would reach 500 km/h in the first half of 21st century.

Shanghai demonstration line is the first Maglev operation line in the world, (Fig.1), which was completely built on December 31, 2002, and began its commercial operation in May 2004. This line is 30km long, in which the German TR technology with the maximum operating speed of 431 km/h was used. Till to May 7, 2006, the Maglev trains in Shanghai line had been safely operated for 1,224 days, though 2.54 million km, and carried more than 6.80 million passengers. Any problem influencing the operation security of the Maglev train has never taken place. The significance and success of Shanghai demonstration line symbolized that through engineering construction and commercial operation, the high speed Maglev technology is on the way into market firstly in China. On March 7, 2005, the Linimo line built for the Expo2005 Aichi Japan, began its commercial operation, and became the second Maglev commercial line in the world after Shanghai line. This line is 9.2 km long, in which HSST technology with 100 km/h maximum operating speed was used.

The successful operation of the Shanghai Pudong Airport Line and Aichi Linimo Line indicated that the Maglev technology development has come into a new period of commercial application.

2. ADVANTAGES OF HIGH SPEED MAGLEV

The history of passenger transport is characterized with the increase of operational speed. Since 1825 when the wheel-rail system appeared, it took 140 years to achieve 200 km/h operation speed. It spent nearly another 30 years to increase speed from 200 km/h to 300 km/h, which is nearly close to the speed limit because of the restriction of friction between wheel and rail, and onboard power supply. High speed Maglev systems eliminated mechanical contacts, which are the main obstacles for increasing the speed of traditional railway, and overcome inherent and unsolved contradictions between drive force & friction, speed & drive power, high speed
operation & safety in wheel-rail systems to realize the flying on the ground without contact and fuel.

The advantages of high speed Maglev technology are experienced and recognized by more and more people from Shanghai demonstration line. These advantages already approved are:

1) High Speed

It is the only high speed ground transport system with 500 km/h operating speed at present, and has evident irreplaceable advantages.

2) High Accelerating Rates, High Climbing Capability, and Small Curve Radii

Because of application of contactless guidance and drive, the accelerating rate, climbing capability, and the curve radius of Maglev system are determined by electrical power, not by friction between wheel and rail like the traditional train. The accelerating rate of Maglev system may reach up to 1-3 m/s², for example, vehicles in Shanghai line can be accelerated from 0 to 431 km/h within 3 minutes only. The approved climbing capability of Maglev systems may attain up to 10 %, while it is only 4 % for wheel rail systems. The curve radius of Maglev system is smaller than high-speed wheel-rail system at the same speed. As a result, it can shorten the route, use less soil, and reduce the total investment.

3) Safe and Comfortable Riding

Owing to the mechanic and electrical structure of high-speed Maglev system, the dangerous accident of derail, happened in traditional train, may not occur. Eliminating mechanical contacts made it possible to realize calm operation, small vibration, and comfortable ride. The usable rate of 99.83 % and operating punctual rate of 99.57 % in Shanghai line, including normally commercial operation under the 30 m/s typhoon condition, are the best evidence of safety and reliability of high speed Maglev systems.

4) Little Maintenance

Owing to uniform force distribution and no abrasion, small maintenance in Shanghai line is to examine and change the electronic module with something wrong, but vast work on replacing and repairing mechanical parts in traditional rail are not required. Along with the development of electronic industry, the reliability of electronic devices will be improved gradually, and the maintenance should become simpler and easier. Little maintenance is a key issue to reduce the cost of operation and investment.

5) Friendly to Environment

Electrical driving in Maglev systems eliminates emitting of baneful gas and environment pollution. Elevated guideway use less soil land. Magnetic fields in the passenger cabin of Maglev trains are equal to Earth’s, smaller than color TV’s.

3. APPLICATION AREAS OF MAGLEV

In past 30 years, varied types of Maglev technology using different modes of levitation, propulsion, and controlling systems have been studied and developed in the world. Based on the difference of operation speeds, there are two kinds of Maglev technologies: high-speed and medium-low speed Maglev. At present TR technology from Germany and Express technology from Japan are mature high speed Maglev systems in the world. The HSST technology is a mature medium-low speed Maglev system. Two kinds of Maglev systems are used in different areas respectively.

The High speed Maglev system is a new type of transport tool filled up the speed gap between high-speed trains (300 km/h) and airplanes (over 700 km/h). The appropriate travel distance of high speed Maglev system with the maximum speed of 500 km/h is 500-1500 km, in which the travel time is within 3-4 hours. In this distance called the “sweet spot”, travel time by Maglev is equal to or less than airplanes. The advantages of obviously shortening travel time by high-speed Maglev systems can fully be represented. In the market operation, travel distance for Maglev should not be less than 240 km or longer than 1500 km, because the traditional train and airplane will weaken the comparative advantage of high-speed Maglev.

Different from the long distance trunk line the medium-low speed Maglev system is suitable for urban rail transportation. In the development of urban transport system, more attention should be paid to these items: (1) the restriction to noise is very sensitive and strict. (2) In a short distance between two stops a high operating speed is not necessary. (3) Urban transport must meet the needs of small space, various terrain, and existing buildings, and minimize removing. (4) Considering the great social need and the high cost and slow development of subway, urban transport should not be too expensive.

The advantages of calm operation, high accelerating rate and climbing capability (7-10 %) and small curve radius (50-70 m) made it very competitive to apply medium-low speed Maglev system in urban transport. If cost is reduced significantly, the system must have vast and bright developing foreground.

4. MARKET OF MAGLEV’S DEVELOPMENT

1) Development of Maglev in the World

Germany is the first country developing Maglev technology in the world. Mr. Hermann Kemper put forward electromagnetic suspension theory in 1922 and obtained the patent in 1934. Germany industry invested by German government began R&D work
in 1960’s. In 1991, Germany announced that TR technology had been mature and decided to build the Berlin-Hamburger line in April 1997 which was given up in February 2000. At the same time, the Dortmund-Düsseldorf line and Munich airport line went into the feasibility research phase. The Dortmund-Düsseldorf line was given up in 2003. In August 2005, after the Munich line went into the design examining and approving phase, the German government and industry group signed a contact to continue Maglev technology research in order to improve technology performance, enhance system economy, and enlarge TR application.

In America, air transport and highway are extended to everywhere, and railway is in a chronic degression. Recently the transport mode of planes plus cars brought traffic jam, delay, accident and air pollution which thereout produced a great deal of serious social problems of energy consumption and environmental breakage. In 1992, Department of Transportation implemented National Maglev Initiative (NMI). Transportation Equity Act for the 21st Century was issued in 1998, which stipulated in the legal form to develop Maglev transportation systems in USA. In August 2005, the reauthorization of TEA-21 named SAFETEA was finally completed and $90 million in additional funding was allocated to the Maglev Deployment Program using TR technology. This funding is to be divided evenly between the California-Nevada (Las Vegas) Project and one of east coast Maglev projects to be chosen.

In 2005 The UK government wanted to build a high-speed Maglev line from London to DDI and Glasgow. At the same time, another Maglev project from Singapore to Kuala Lumpur, the capital of Malaysia, was proposed. Qatar government decided to do feasibility research about building a TR Maglev line linking to United Arab Emirates.

Japan is engaged in developing super-conducting Maglev systems for a long time. The 18.4 km test line (double track) was built at Yamanashi in 1997. The MLX001 and MLX002 broke the world’s record for ground transport speed with 580 km/h. In August 1999, the evaluation made by Ministry of Transport verified that there are no problems for actual applications but further improvement on vehicle aerodynamics and operating performance reducing noise and aerodynamic vibration is required. The plan to build Tokyo-Osaka decided in 2004 was delayed. In 1993 HSST technology used for airport connection and urban transportation was passed the evaluation by the Ministry of Transport on Oe test line built at Nagoya in 1991 and eventually went into market. The Linimo (Fig. 2) line began its commercial operation on March 7, 2005, the eve of Expo 2005.

Late 1980’s China began the study on key technology of low speed Maglev and economical feasibility. In 1999, consensus of developing high-speed Maglev technology and building a test line was acquired by scientific and technological group and accepted by government. China and German signed a contract to conduct jointly feasibility research on building Shanghai demonstration and operation line on June 30, 2000, and the contact of Supply and Service for Shanghai line on January 23, 2001. The construction of Shanghai line began on March 1, 2001. Ceremony of single track test operation with 430 km/h operating speed was held on Dec. 31, 2002. Max test speed of 501 km/h was achieved on Nov. 11, 2003. The normal commercial operation began in May 2004. At the same time, R&D of high-speed Maglev, as a main project was included in National High-Technology R& D (863) Program and National 10th Five Year Plan (2001-2005).

2) Market Demand Is the Driving Force of Maglev’s Development

The progress of Maglev development in the world showed that market demand is the mainly important driving force. Germany and Japan took the lead in R&D of Maglev system. However, Germany and Japanese conditions of small country acreages with greatly developed aviation highway, especially the high-speed railway system determined that it is difficult to develop a new Maglev system for the intensive opposition from these industries consequentially.

China needs high speed Maglev which is based on the condition and market demand of our country. China has a wide territory and large population. Chinese economy is at sustaining and fast development and Chinese people’s living standard is rapidly increased. On the other hand, China is lack of oil, and Chinese oil reservation per person is only 11 % of average reservation in the world. The transport mode of planes plus cars does not accord with the condition of China. The existing railway system with 100 km/h operating speed doesn’t satisfy fast increasing needs. According to the plan of transportation, in 2050 Chinese population will be 1.47 bil-
lion, and over 75% people will live in cities and towns. The scale of railway network will increase from 65 kilo km to 120 Kilo km in which 8 kilo km will be a high speed network for passenger transportation. The distance of main passenger transport line linking large cities is mostly over 1000 km. High-speed Maglev systems with 500 km/h have obvious advantages for high-capacity long-distance passenger transport between large cities for realizing comfortable travel of 800-1500 km within 3 hours, sharing the ridership of cars and planes, and reducing oil consumption.

High speed Maglev will be first used in fast developed regions or city group as intercity truck transport in Yangtze River Delta, which is one of three leaders of economical development of China, to accelerate the fast increase of regional economy there. After a long time’s argumentation, the feasibility study on Shanghai-Hangzhou Line was decided to be conducted. The line would be constructed this year and operated in 2010, which will be the first intercity Maglev line in the world, and must be a new milestone of Maglev’s development.

Along with the fast development of cities and towns, urban transportation in China became the choke point restricting social and economic developing for the traffic jams and air pollution in large cities. The track transport system with high capacity is the effective means to solve these social problems. It is foreseen that thousands of kilometres track transport line is planed to build in 35 cities with over million populations, which will form another huge market. It is necessary to break up single developing mode of too expensive subway and introduce advanced and appropriate multiple urban transport systems. If the cost of medium-low speed Maglev system could be reduced successfully, another large market of Maglev may be also in China.

5. MAGLEV’S DEVELOPMENT FACING CHALLENGE

Maglev system passed through basic research and engineering developing phases, and is located in the phase of construction of practical operational line and commercialization of all equipment. There are a lot of technical and economical problems in construction practice to be solved and operating experience to be accumulated.

After 30km test or demonstration line, to build 100-200km operating line is a necessary developing phase and a reasonable choice without big risk to build a long-distance line. However in this short distance it is very difficult for high speed Maglev system to bring its advantage and potential into play for the limited shortening travel time, even in the dense population corridor where return of investment would most possibly be gotten. However, in this distance the high-speed wheel-rail technology, more mature than Maglev, can get the same or even more transport and economic benefit with less investment. In Germany, through many years’ prephase preparation including primary engineering design, the Berlin-Hamburger line was given up at last in 2000. In USA, preliminary feasibility research on candidate Maglev operation lines continued for many years, but the decision to build an operation line has not been made yet now. The facts above indicate that successfully building 100-200 km operating line is the key and unavoidable step of development in which high-speed Maglev is facing severe challenge from traditional high-speed wheel-track technology. The successful construction and operation of Shanghai demonstration line have already fully proved that the high-speed Maglev system is safe and reliable, but the unit price of investment is high (RMB 300 million/km). The unit price of investment of five candidate projects using TR technology in USA and German Munich line are ever higher than Shanghai line.

The economic feasibility, i.e. whether the cost can be reduced, decides whether the Maglev technology can go into market. The decrease of cost is determined by the course and scale of industrialization. Moreover the industrialization scale lies on market demands. They are interacting and become a vicious circle restricting high-speed Maglev technology development at the present. Only by breaking the vicious circle and forming a nice promoting circle based on strategic decisions, can it be possible to develop high-speed Maglev systems into large-scale application.

Similar to high speed Maglev, the development of medium-low speed Maglev technology is also facing competition with traditional wheel-rail technology in urban transportation where the market requirement is great. There are many types of wheel-rail transport tools usable for urban transportation including subway, light rail, monorail, liner motor propulsion system, and so on. Different from high-speed Maglev, the medium-low speed Maglev doesn’t have irreplaceable technology advantages. Moreover there are some problems about energy consumption, over load capability, investment etc to be solved. This is why success of HSST is earlier than TR technology, but began its revenue service until March 2005.

6. NEW MAGLEV TECHNOLOGY

The main reason why it is difficult for the German TR, Japan HSST and Express Maglev technology to
be industrialized and go into market at the present is that the cost is higher than wheel rail technology. There are many independent R&D works for improving technology performance and reducing system cost, including theory innovation, computer simulation, key parts manufacture and technology economic analysis. Many useful productions have been acquired, although most of them are still at the phase of idea design and theory model test, these new ideas, materials, and designs are worthy of attention.

1) Electromagnetic Switch

The switch configuration of TR, Express and HSST are complicated and hulking. The switching time is longer than traditional technology for the moving part depends on track elasticity distortion. They result in building large station and maintenance base. Fig. 3 is the non-mechanism movement electromagnetic switch introduced by Magplane. Dr. James Powell and Gordon Danby, the father of super-conducting Maglev of America, invented the second generation of super-conducting Maglev technology. Maglev 2000 has four characteristics: quadrupole super-conducting magnet, narrow girder (< 1.22 m), plane guideway and high speed electromagnetic switch.

Fig. 3: Electromagnetic Switch of Magplane

The quadrupole super-conducting magnet has both vertical and horizontal magnetic fields as shown in Fig. 4, which is the core of the four characteristics.

Fig. 4: Quadrupole Magnet of Maglev 2000

2) Hybrid Levitation System

The 10mm levitation gap in the TR system requires high guideway precision of millimeter level. This made the whole system too expensive. The hybrid levitation technology scheme as shown in Fig.6, using permanent and electrical magnets, was introduced by Magnemotion to increase the levitation gap, reduce guideway precision, and lighten guideway weight. The M3 minitype test device was built and theory test was completed. A 200 m line of demonstration system will be built.

Fig 6: Permanent and Electromagnetic Levitation System of Magnemotion
The GA developed a Maglev technology using permanent magnet, electrodynamics Suspension, liner Synchronous Motor, and independent levitation and drive system.

Fig. 7 shows the test platform. The magnet adopts double-layer Hallbach Array structure. It can simulate a line speed of 45 m/s (about 160 km/h).

GA built a 120 m test line with 50m curve radius and prototype vehicle with 10m/s maximal speed, 1.7 m/s² accelerating rate using 3MW IGBT power supply (Fig. 8).

A 4.5 mile demonstration line with 7 % grade will be built at California University of Pennsylvania. The cost per track is about 25 M$/km. It will operate in 3 to 5 years.

3) High Temperature Super-conducting Maglev

Japan conducted research on using high temperature super-conducting materials into a Maglev system. Compared with the low temperature super-conducting Maglev, the high temperature super-conducting Maglev has advantages of simpler cooling configuration, low cost, and better stability.

On December 13, 2005, Central Japan Railway Company announced that the high temperature super-conducting Maglev was tested successfully. The operation speed is 553 km/h. The levitation gap is 10 cm. It is a significant progress for large-scale application of high temperature super-conducting transportation systems.

7. CONCLUSION

The advantages of Maglev are known by more and more people through two demonstration lines in China and Japan. Although there are many difficulties and risks, Maglev as a new type of transportation tool for the 21st century, would become more and more mature and perfect in engineering and commercial application and must have a wide development foreground.

8. REFERENCES
