MLADEN NIKŠIĆ, B.Eng.
VESELKO PROTEGA, B.Eng.
DRAGAN PERAKOVIĆ, B.Eng.
Fakultet prometnih znanosti,
Vukelićeva 4, Zagreb

Traffic Engineering
Review
U.D.C. 652.3:621.318
Accepted: Oct. 28, 1997
Approved: Jan. 30, 1998

THE DEVELOPMENT PROSPECTS OF MAGNETICALLY LEVITATED TRAINS

SUMMARY

The paper analyses the up-to-date research in developing magnetically levitated (MAGLEV) motorcars. It presents the historical overview of the development of the most famous magnetic levitation systems of today.

Apart from describing the operation method and the technical features of each system, the paper analyses the advantages and drawbacks of certain systems, as well as the advantages and drawbacks of magnetically levitated motorcars compared to conventional railway.

The paper presents the plans for the future as well as the systems which have the highest prospects of being also commercially and not just experimentally used.

1. INTRODUCTION

Since the construction of the first railway trains based on the propulsion by adhesion along the rail, nothing much has changed: support, guiding, acceleration and braking have been performed via wheels and rail track. However, the possibilities offered by this method are limited: on one hand the higher speed increases the friction as well (thus also affecting the energy expenditure and the wear of components), and, on the other hand, the adhesion force is reduced to such an extent that at a speed of about 350 km/h the wheels start sliding in normal conditions. Therefore, the use of conventional railway cars is not suitable for speeds above 300 km/h.

In Maglev (magnetic levitation) technology, the electromagnets for support and guidance take over the function of wheels and rails. Thus the train can run without any contact with the surface.

There are two versions of Maglev technology which are being intensely studied: electromagnetic and electrodynamic system. In the electromagnetic principle the vehicle is attracted to the rail, i.e. to the guideway by support electromagnets. This is achieved by intermittent action of stator packages located beneath the car. The guiding electromagnets located on the side keep the car on the track. The electrodynamic principle uses the repulsive force of supra-conducting electromagnets in which the stator coils are installed along the guideway sidewalls. Very extensive research has been going on over the past several years in this field, which have resulted in concrete designs. Countries active in this field include: China, Germany, France, Great Britain, Italy, Japan, Canada, Korea, Russia, Switzerland, and the United States of America. The most developed are the versions in Germany and Japan, and their test tracks have matured into sections ready for commercial applications. Both countries use the propulsion by electric motors with long stators which are used both for the non-contact propulsion and for braking, although various electromagnetic technologies have been applied. Japan and Korea have also developed Maglev systems which run at lower speeds, using electric motors of short stator fitted in the vehicle.

2. VARIOUS VERSIONS OF MAGNETICALLY LEVITATED TRAINS

2.1. Transrapid - Germany

2.1.1. Historical Development

Here is a summary of the most important data in the history of development of the magnetically levitated trains in Germany.

1922- Hermann Kemper, an engineer from Hanover presents the first ideas about a magnetically levitated train (on the principle of attraction), and starts with the development.

1939 to 1943 - Hermann Kemper starts working on the magnetically levitated vehicle at the Aerodynamic Institute in Göttingen. It was to achieve a speed of up to 180 km/h on the 20 km long track by Landsberg, using turbine propulsion with no contact with the surface. Since there were no air-tunnels at that time, this kind of vehicles had to be tested on aircraft models.

1962 - Prof. W.Bäseler suggests the principle of rolling transporters that would reduce the load on the roads. The cars move over rolling transporters which bring them at high speed to their destinations.

1969 - Transrapid 01 is constructed by Krauss-Maffei; the first functional non-contact magnetically levitated train with a short stator propulsion (the propulsion is fitted in the vehicle).

1971 - Messerschmitt-Bölkow-Blohm (MBB) presents the first passenger vehicle with magnetic levitation technology, reaching the maximum speed of 90 km/h.

1971-1974 - Development and testing of air cushions and levitating vehicles with constant magnets for high speed systems. These two developments are to be later discontinued due to technical problems i.e. predictable difficulties regarding economic and ecological aspects.

1974 - The Institute for Electrical machines, plants and railways (IEM) at the Polytechnic University in Braunschweig, in co-operation with Thyssen Henschel, starts research in the field of electromagnetic driving technique. The aim was to develop magnetic vehicles with linear electric motor with a long stator. Since almost all test vehicles had up to then been propelled by the short stator technology, where the motor is fitted in the vehicle, this propelling system was at that time regarded as alternative. The long stator technology, where the propulsion is attached to the guideway itself, has among other things the advantage of not requiring electric power take-offs. Low amounts of energy needed by the vehicle, can be taken without contact over the linear generators, from the magnetic field of the track itself.

1979 - Specially for the International Traffic Show in Hamburg (IWA '79), built Transrapid 05 was the first magnetic vehicle with a long stator, in the world, for transporting passengers. On a 908 m long track, 36 ton vehicle with 68 seats, transported about 50 thousand visitors at a maximum speed of 90 km/h.

1984 - Work with Transrapid 06 could start when the first part of the test track TVE was finished (Transrapid Versuchsanlage Emsland) 20.6 km long, consisting of a straight section (about 7 km) and a northern curve (radius 1690 m). After completing TVE in 1987 (by constructing the southern curve of 1000 m radius), Transrapid could use a 31.5 km long, in the world unique, testing track. In 1988, the speed of 400 km/h was exceeded.

1993 - Transrapid 07 reaches the new world record of 450 km/h, in normal operating conditions.

2.1.2. Technical Characteristics of Transrapid

Transrapid is the magnetically levitated train which uses the principle of electromagnetic repulsion. The levitation system and the propulsion system are based on the attracting forces of the electromagnets located on the underframe of the vehicle and stator packages located beneath the guideway platform (Figure 1). The support magnets located beneath attract the vehicle to the guideway and the guidance magnets keep it laterally on the track. Support and guidance electromagnets are located on both sides along the whole vehicle length (Figure 2). Highly reliable electronic control system provides guidance and support of the vehicle at constant distance of 10 mm from the track. The levitation system, that is the instruments on the vehicle itself are supplied by energy without any contact, over the linear generators located in the support electromagnets. Therefore, Transrapid does not need any contact cables nor electric energy take-offs.

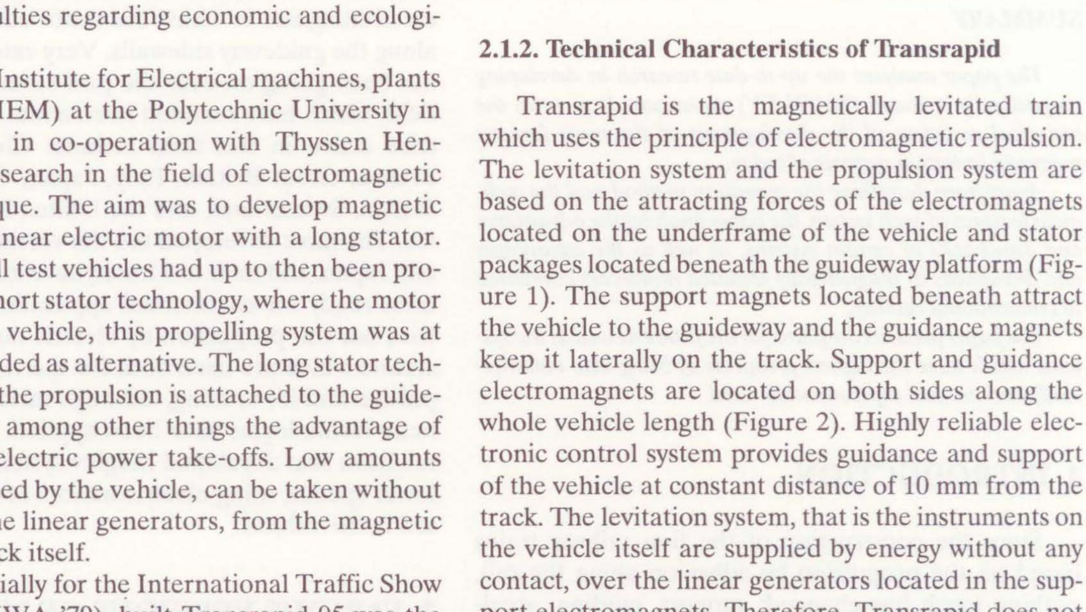

Figure 1 - Vehicle-guideway Components

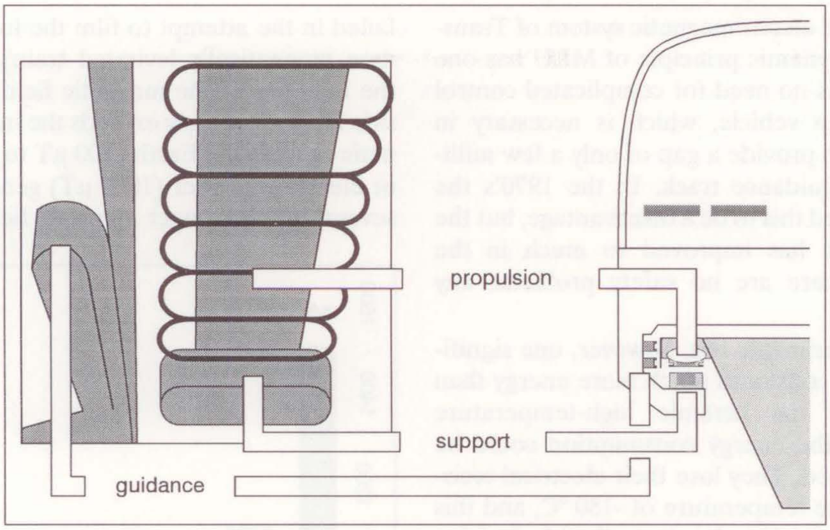

Figure 2 - Principle of propulsion

Magnetically levitated high speed train is propelled by synchronous linear electric motor with a long stator. Its principle of operation is similar to a rotary electric motor whose stator is like an extended cable on both sides of the guideway. Instead of generating rotary magnetic field, the current in the coils generates a longitudinal-movable magnetic field. Magnetic field excites the support magnets thus attracting the vehicle and causing it to move without any contact. The traction force and the vehicle speed are proportional to the frequency and the voltage of the synchronous linear electric motor. The synchronous propulsion with a long stator enables constant acceleration up to the travelling speed when operating as electric motor, and when operating as generator, constant deceleration until stopping. The propulsion can be continuously controlled within the total area of operation by means of frequency switches in the plant, and the braking power can be re-used by re-entering the electrical network.

The propulsion of the conventional means of transport is located in the vehicle, and full engine power is required only at few sections. During the rest of the drive there is no need for the full engine power and it presents a burden. However, in magnetically levitated trains, the propulsion is located in the guideway. This provides two main advantages: the vehicle is much lighter, and the propulsion can be used flexibly. Thus, at inclines i.e. sections which require acceleration, greater power is used than at flat tracks. The current is always supplied to that part of the electric motor at which the vehicle is currently located. After the vehicle has passed a certain section, it is automatically re-directed to the next section of the electric motor. The left and the right halves of the electric motor are used to reduce the differences in the thrust forces, that is, they are arranged with a certain spacing.

2.2. MLU - Japan

2.2.1. Historical Development

1962 - research starts on non-contact propulsion with linear electric motor.

1972 - test vehicle with linear electric motor (LSM 200) successfully completed the first run as well as the vehicle propelled by linear induction electric motor ML 100.

1979 - the speed of 517 km/h reached.

1987 - test runs begin with vehicle MLU 002.

1989 - MLU 002 reaches the speed of 394 km/h.

1991 - test runs start with lateral levitation systems.

1993 - first test runs begin with the vehicle MLU 002N.

1994 - MLU 002N reaches the speed of 431 km/h.

1997 - MLX 01 vehicle reaches the speed of 451 km/h on the Yamanashi Test Line.

2.2.2. Technical Characteristics of MLU

MLU is based on the electrodynamic levitation system: supra-conducting magnets of the vehicle and the magnets located on the inner wall of the guideway repel each other. In order to achieve the extremely high magnet conductivity, the coils in the vehicle are cooled by the liquified helium to a temperature of -270C.

MLU floats on a magnetic cushion, whereas Transrapid is pulled forwards by the magnets in the guideway. There is one more difference: while Transrapid floats from the very beginning, MLU travels on auxiliary wheels up to the speed of over 100 km/h. It is only then that it lifts and floats at a height of 30 cm above the guideway which has the form of the letter U. Because of the relatively wide gap toward the concrete path, such vehicle would have no accident in case of an earthquake (a very frequent phenomenon in Japan).

Compared with the electromagnetic system of Transrapid, the electrodynamic principle of MLU has one advantage - there is no need for complicated control electronics in each vehicle, which is necessary in Transrapid so as to provide a gap of only a few millimetres from the guidance track. In the 1970's the Japanese considered this to be a disadvantage, but the control technology has improved so much in the meantime, that there are no safety problems any more.

The Japanese principle has, however, one significant drawback - it consumes much more energy than Transrapid. With the ceramic high-temperature supra-conductors the energy consumption could be substantially reduced. They lose their electrical resistance already at the temperature of -180 °C, and this temperature is attained by the cheap liquid nitrogen. Therefore, German engineers could give up their complicated control electronics, the vehicle would not have to span the T-like guideway, thus making the switches simpler and the track construction less expensive.

Unlike HSST and Transrapid, MLU of the Japanese Railway is based on the electrodynamic principle. The propulsion is located in the vehicle, and unlike the German levitated train, the magnetic forces repel the train upwards and at the same time forwards in the direction of travelling. The advantage of this method is that MLU does not require any active regulation of the magnetic field. If the train comes nearer to the guideway, the laws of physics repel it with more intensity, thus, in fact, being balanced at a constant height.

The up-to-now maximum speed of MLU amounted to 451 km/h, and MLU can compete with Transrapid only if it eliminates a whole range of drawbacks. These are, first of all, much greater costs of the track construction. Whereas Transrapid includes a relatively narrow supporter, the case with MLU is completely different. The guideway is in the form of the letter U. Such a big structure which substantially complicates the construction of switches also affects the adaptability of the run track.

Furthermore, the MLU magnets have to release a lot more power, since power at a lower level can be used due to the electrodynamic system. Up to now this problem has been solved by supra-conducting magnets cooled to below -270 °C. With the new "high-temperature" supra-conductors the temperature can be reduced to -180 °C, with the energy consumption remaining high.

Without taking into consideration the produced electro-smog, passengers with pace-makers or insulin pumps should not use the train because of the strong magnetic fields, and interference with other electrical devices are also possible (the Austrian television crew failed in the attempt to film the interior of the Japanese magnetically levitated train). For comparison: the intensity of the magnetic field in Transrapid, inside the train, barely exceeds the intensity of the magnetic field of the Earth (100 μT to 60 μT); hair-dryer or electrical cooker (1000 μT) generate for example, several times stronger magnetic field (Figure 3).

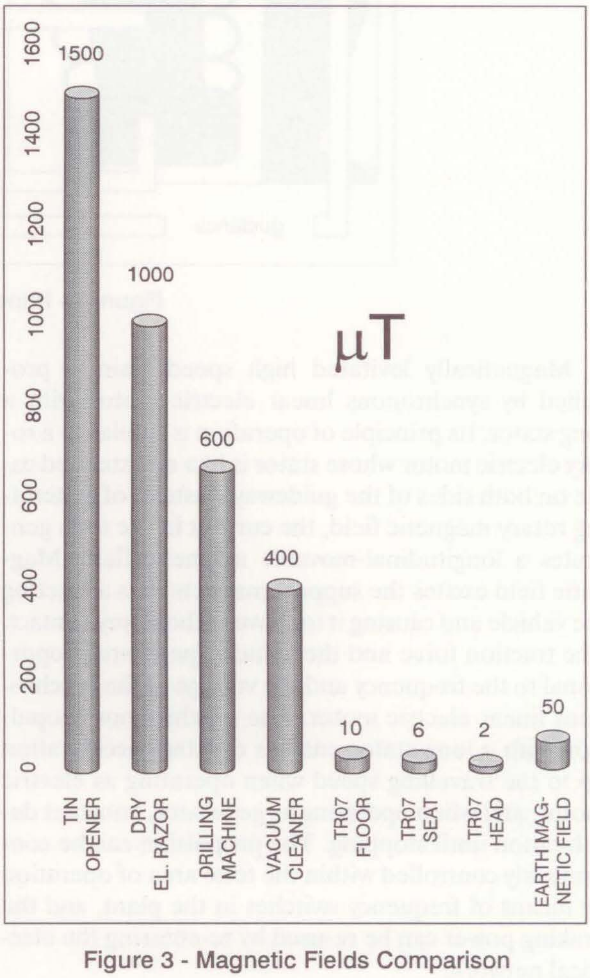

Figure 3 - Magnetic Fields Comparison

In spite of a strong magnetic field, MLU starts to float freely only at a speed of over 100 km/h. Until then it has to use auxiliary wheels causing certain wear due to friction. Because of the still lacking magnetic field, MLU cannot yet reach the level of Transrapid regarding riding comfort.

2.3. HSST - Japan

HSST is magnetically levitated system which has been developed in Japan by the HSST Development Corporation, and is now being offered around the world. Two of the major shareholders and founders of the corporation are Japan Airlines and Nagoya Railroad Company Ltd. This corporation was established in 1993, but the development had started much earlier.

2.3.1. Historical Development

As early as *1972* Japan Airlines started developing a transportation system which would enable fast access to the airports.

In *1975*, the first vehicle with 2 passenger seats - HSST-01 was produced.

In the period between *March and September 1985*, demonstration runs took place at Tsukuba Science Expo, carrying a total of 610,000 passengers. The vehicle was named HSST-03 and had 50 seats.

Between *March and May 1988*, during Saitama Expo in Kumagaya, the next HSST-04 vehicle (70 seats) carried about 240,000 passengers.

In *1989* at Yokohama Expo, HSST-05 (a 2-car train and 150 seats) began commercial operations. Between March and October it carried 1.26 million passengers.

In *May 1991* Chubu HSST Development Corporation began test runs of the HSST-100. This vehicle was actually developed from the co-operation of the partly private sector of Aichi Prefectural Government, Nagoya Railroad, and HSST Corporation. HSST was assessed by two committees: one, from the point of view of the magnetically levitated trains technology and the other, from the point of view of using the linear electrical motor propulsion in magnetically levitated trains in suburban traffic.

In *1995* the vehicle HSST-100L was completed (an extended 2-car model).

In *May 1995* the new vehicle started test runs. The next month a contract was signed for the vehicle HSST-100L on the 5.3 km long track between Ofuna and Yokohama Dreamland.

2.3.2. Technical Characteristics of HSST

HSST is a magnetically levitated train for passenger transportation in suburban traffic system, at speeds of 200-300 km/h. HSST technology is based, like Transrapid, on the principle of attraction. However, the propulsion is not fitted in the guideway, but in the train, so that a contact cable is required. Besides, support and guidance of the vehicle are integrated in one unique system (otherwise these are two separate systems). Due to these special features, HSST cannot run at speeds higher than 300 km/h.

The HSST principle is based on simple direct-current electromagnets that are attached to the bottom of the vehicle and lift it upward toward a ferromagnetic rail thus enabling levitation. Sensors measure the gap (distance between the vehicle and the guideway) and keep it at the given 8 mm. In case of deflection, the control system reacts by varying the voltage which acts on the electromagnets to return to the required distance between the vehicle and the track.

The vehicle consists of six modules, and each module has a bogie, similar to conventional cars, thus enabling easy and smooth guidance. Each module has four electromagnets, one linear electric motor with a short stator and one braking mechanism. The source of energy is the direct-current 220 V source. It is not propelled by conventional rotary electric motors, but by linear induction motors (LIM), which is one further difference compared to other systems, since this is the electric motor of a short stator. The primary coil, the stator package, is mounted on the vehicle module, and the secondary coil in the form of an aluminium plate is installed along the guideway rail. The traction force and the speed are controlled by varying the frequency and the voltage. The electric motor of the short stator provides continuous acceleration up to the running speed as well as constant deceleration to complete halt.

2.4. "Seraphim" Project - the United States of America

The USA started to develop magnetically levitated trains in **1971**. In **1974**, a vehicle in Colorado set the world record of that time, with 411 km/h. A year later, the USA discontinued this development. In the meantime, they realised the great significance of the magnetic levitation technology and with the "Seraphim" project in **1994**, the development of previous research continued.

The main drawback of the German and Japanese levitating trains is their incompatibility with the conventional railway tracks. Because of the magnetically levitated trains, new tracks have to be built since the old ones, that is the railway lines, cannot be used. The USA is trying to overcome this problem by the Seraphim project (short for Segmented Rail Phased Induction Motor). The train would levitate, using the coils attached to its floor, above the aluminium tracks. The aluminium tracks could be attached to the existing tracks, either between or along them, thus making savings per track sections. The train is self-supplied by energy - gas turbine in the traction car produces the electric current necessary for propulsion.

A Seraphim prototype has not been constructed yet, and the system was tested only on laboratory models. For the moment, the construction of a real size traction car has been planned, and it would be tested in Colorado. A lot of research work is still needed for this kind of system, most of all because of the regulation and control technology. Because of the built-in gas turbine, Seraphim will surely produce more noise than Transrapid. Besides, it is still a question whether the existing tracks will accommodate the load of a train running at 500 km/h or whether new tracks will have to be built after all. Even the high speed trains, such as ICE and TGV run on specially constructed tracks that do not cost less than one Tansrapid track.

2.5. "Swissmetro" Project - Switzerland

With the "Swissmetro" project, Switzerland is planning the construction of the whole network of underground magnetic tracks. Since this country of the Alps is pre-destined to build tunnels, the intention is to link major cities, often 40-80 km apart, by magnetically levitated trains that would travel through the mountains - through tunnels.

These trains would run on the well known electromagnetic principle of Transrapid i.e. by propulsion in the guideway. The Swiss are trying not only to eliminate the drag due to friction caused by wheels but also that due to air. There would be partial vacuum in the tunnels which would almost completely eliminate the air drag. This means that the trains would spend much less energy at speeds of 400-500 km/h than ICE or TGV at much lower speeds.

The construction of tunnels will be of no special problem for the Swiss, thanks to their great experience in the field, but, nevertheless, they will have to spend on this part 75% of the overall project costs. Until now the whole project is still a theory. However, the construction of an 800 m test track was supposed to begin at the end of last year.

2.6. HML - Korea

The Korean HML system is based on electromagnetic attraction and propulsion by linear induction motors. The current vehicle marked HML-03 is a prototype that has been in operation already since *1993*. Its capacity is 40 seats and it was designed primarily as a public transport vehicle for regional suburban traffic, running at speeds of up to 150 km/h. The development started in the late *80's*, at the Hyundai Precision & Industry Co. Ltd. The HML-03 vehicle, demonstrated at the Taejon *1993* exposition, ran already at that time at a speed of 50 km/h on a 560 m long track.

This vehicle levitates without contact with the surface based on electromagnetic effect of the support and guidance magnets. Running, acceleration and deceleration are realised by linear electric motors installed in the vehicle. Safety air brakes have been additionally installed, not depending on the propulsion system. According to the current plans, a version for high speeds will be constructed, which would connect the cities in Korea at speeds of 200-300 km/h.

3. ADVANTAGES OF MAGNETICALLY LEVITATED TRAINS

The development and implementation of the new traffic system is justified only when it provides advantages for the user, carrier, and when the traffic system is environmentally friendly. The most important criterion for the owner is the economy, and certain influencing parameters can be presented in the following way.

In the case of Transrapid, the track itself takes up about 70% of the total investments in the new line. Although this already includes the propulsion elements in the guideway, the construction costs of Transrapid tracks in the flatlands can be compared to those of high speed railway lines. In topographically demanding, as well as in densely populated regions, the investment in the track itself is, based on the ability to adjust (greater possibilities in tracks-planning) even lower.

The costs for the Transrapid vehicles are somewhat higher than with high speed trains (e.g. ICE). In considering the concrete cases, however, it can be concluded that the investments in the necessary rolling stock are, depending on the seats and kilometres, by 25% more in favour of Transrapid. The reason for this are the greater revolution speeds, resulting in higher speeds, shorter acceleration times which enable better utilisation of each vehicle. Depending on the volume of traffic, trains with up to 10 units can be used. Each unit has on average 90 seats. Cargo is transported in container units which have useful capacity of 17 t. Passenger and cargo units can be combined in combined vehicles.

The comparison of investment costs goes even more in favour of Transrapid in considering the exploitation costs. The magnetically levitated train has no wheels, axles, transmission mechanisms, no mechanical brakes, and no electric current take-offs. Instead of mechanical parts which precisely at high speeds suffer from increased wear, electric components are installed i.e. electronic parts which have no problems with wear. This alone reduces significantly the maintenance costs of the vehicles and the guideway.

The same applies for the consumption of energy. Because of good aerodynamics and non-contact technology, Transrapid consumes at the same power about a third of energy of the conventional rail systems (Figure 4) which are already low consumers of energy. At the speed of 300 km/h Transrapid consumes as little as 38 Wh per seat and per kilometre. In comparison, high speed trains consume 70 Wh. This enables economic

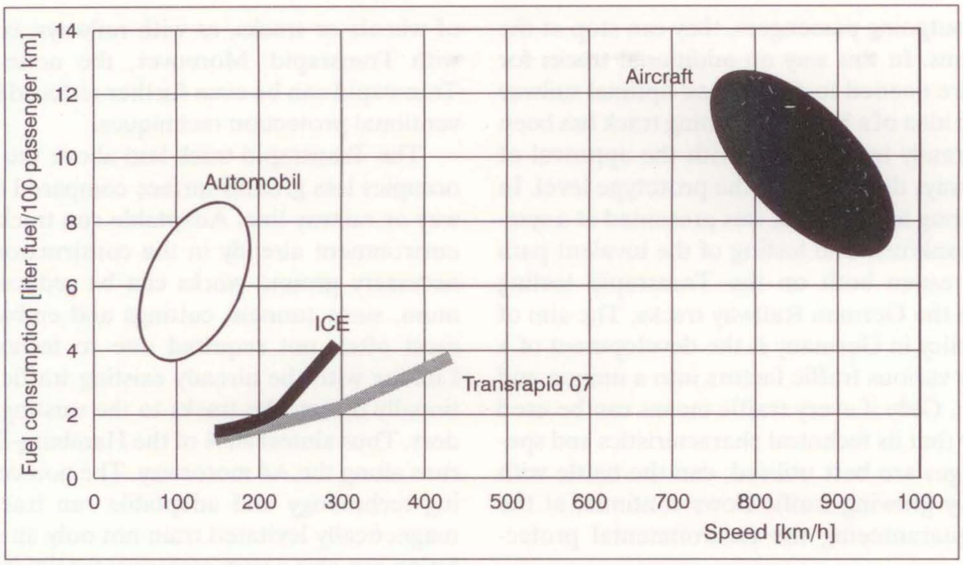

Figure 4 - Different Transport Systems Energy Requirement

exploitation at a price that would be regarded as normal in modern railway systems.

At the approximately same tariffs, Transrapid offers substantially more to the passengers. The ratio price / advantage is thus greatly improved, at the same time improving the position of railway in the market competition with other traffic systems. The user is provided with the following advantage: magnetically levitated train runs, or better, floats at speeds of 300-500 km/h, at the same time being safer than any other traffic means. The reason lies in the fact that the safety risks of the conventional traffic systems are known and they could be predicted and taken into consideration in developing the magnetically levitated trains. For example: the vehicle spans the guideway, so that leaving the rails is completely eliminated, and since there are in general no intersections on guideways, there can be no collisions with other vehicles.

At medium distances, the time of travelling by Transrapid is shorter than the time of travelling by plane, and at greater distances (up to 800 km) the times are approximately equal. Compared to high speed trains the advantage gained in time with Transrapid is even greater. Thus travelling with high speed trains from Hamburg to Munich takes six hours, whereas the magnetically levitated train would take only three and a half hours to travel the same distance. Short run times are only partially the result of high travelling speeds. Due to the specific propulsion system, the magnetically levitated train has an extreme capability of acceleration in the overall range of speeds. Thus, Transrapid reaches the speed of 300 km/h in as little as 2 minutes or at a track of 5 km. Even the high speed trains, such as ICE, need for this a track of more than 30 km, and take almost four times longer. At decelerating over a period of two minutes, the run time by Transrapid, compared to run without stopping at a speed of 300 km/h, is 4 minutes longer. For comparison - high speed trains will need, under the same conditions, more than 15 minutes. Because of its ability for acceleration, Transrapid can be used, not only for long distances, but also on medium and short-range tracks, as well as in densely populated regions with relatively short distances between two halting points. The more stops and junctions with railway systems, as well as with other traffic systems, the shorter the arrival and departure distances of passengers, thus reducing the run times as well.

The ability of adjusting the track provides the magnetically levitated train with the possibility to be linked with the air traffic in airports and with road traffic, e.g. at points of high frequency. Today, a far greater problem is how to bring the traffic as close to the city centres as possible. This is true both for roads and for railways, but also for Transrapid. The proper track with tunnels could neither always nor everywhere be realised, due to the physical characteristics, reasons of economy, as well as the possibility of accepting such designs. However, in order to make full use of the advantages gained in run times, Transrapid and railway should be united in a powerful union, which in most cases understands their introduction into the city centres and their connection at railway stations. Technically, this is solved by bivalent traffic path at the already existing railway track. This path can be used both by conventional railway trains and the Transrapid vehicles. Joining and separating of traffic paths is carried out by bivalent switches which by design match the known principle of the Transrapid flexible steel switches. In the region of railway stations certain railway system returns to its running track, so that in spite of different widths of vehicles and different rates of incoming and outgoing passengers, they can stop at the same platforms. In this way no additional tracks for Transrapid are needed to develop an optimal railway network. The idea of a bivalent running track has been conceived already in 1986, and with the approval of German railways developed to the prototype level. In 1987 a 12 m long testing track was presented at a symposium in Frankfurt. The testing of the bivalent path has been foreseen both on the Transrapid testing track, and on the German Railway tracks. The aim of the traffic policy in Germany is the development of a network with various traffic factors into a unique and whole system. Only if every traffic means can be used in such a way that its technical characteristics and specific advantages are best utilised, can the battle with the constantly growing traffic flows continue, at the same time guaranteeing the environmental protection.

The factors deciding whether a certain means of transport will be accepted or not, are from long ago not only its economy and attractiveness. Today one of the most important criteria is the extent of its being environmentally friendly.

Non-contact technology makes the magnetically levitated train easily the best regarding quietness. It produces no noise from rolling nor propulsion. Transrapid is therefore, at the speed of 200 km/h almost noiseless. It can noiselessly float through cities and densely populated regions at a speed which is equal to high speed trains. At higher speeds there is the noise caused by aerodynamics. Still, Transrapid is at 300 km/h quieter than InterCity train at the speed of 160 km/h. The noise is even less than with underground train at 100 km/h. Good aerodynamic properties contribute to the fact that the noise level in Transrapid can be considered relatively low even at speeds of 400 km/h (Figure 5). The increase of noise due to the wear of wheels or tracks, as with railways, is not possible with Transrapid. Moreover, the noise emission in Transrapid can be even further reduced by using conventional protection techniques.

The Transrapid track laid above the ground level occupies less ground surface compared to the motorway or railway line. Adaptable run track protects the environment already in the construction phase. The necessary ground works can be reduced to a minimum, since tunnels, cuttings and embankments are most often not required due to technical reasons. Linking with the already existing traffic routes additionally directs the tracks to the existing traffic corridors. Thus almost 80% of the Hamburg-Berlin section runs along the A4 motorway. The non-contact levitating technology and adaptable run tracks make the magnetically levitated train not only an economic solution but also a very environmentally friendly one.

4. CONCLUSION

The railway transport systems, based on the magnetic levitation technology and linear propulsion, can become very interesting traffic carriers of the future, at the same time being environmentally friendly and helping to solve transport problems. Of all the mentioned systems, Transrapid has gone furthest and it is closest to implementation. Here, the technical achievements are efficiently applied, since this means of transport is ecologically acceptable, safe, economically justified and reliable, and it occupies relatively little physical space.

By the year 2004-2005, opening of the Berlin-Hamburg tracks is to be expected, in the total length of 287 km. Transrapid would travel these tracks in 55 minutes, at an average speed of 400 km/h.

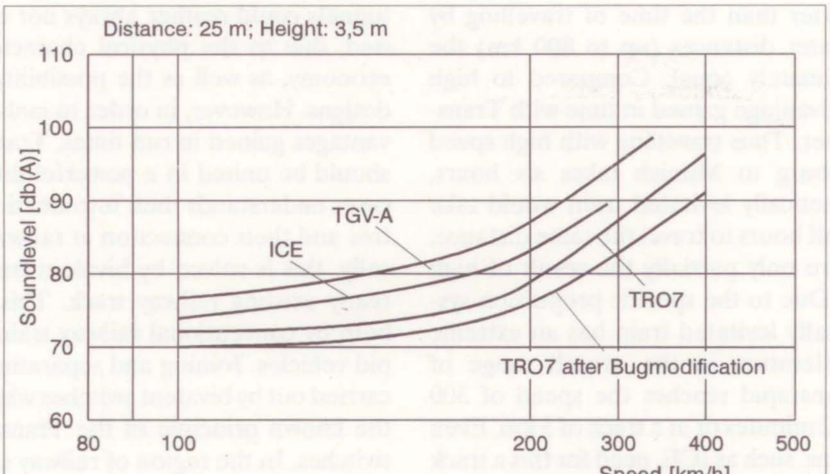

Figure 5 - Noise Emission

Japan plans the construction of testing track in the length of 42.8 km. It would at the same time be the first section of the future tracks Tokyo - Osaka, in the total length of 515 km, partly running under the ground. Besides, the passenger trains between Yamanashi and Tokyo should start travelling next year. The whole tracks Tokyo - Osaka would be constructed by 2005. Because of the partly very high prices of ground, the track in the length of 35 km is constructed under the ground, in order to be economical. Regarding the train, a special aerodynamic prototype of vehicle is being developed whose maximum speed is 451 km/h.

In the experts' opinion, the German train is in development five years ahead of the Japanese one, since MLU has to solve a number of drawbacks.

In 15 years' time, when today's high speed trains such as ICE, TGV and Shinkansen become technically obsolete, the magnetically levitated systems will have to take their place.

SAŽETAK

PERSPEKTIVE RAZVOJA MAGNETSKIH LEBDEĆIH VLAKOVA

U članku se analiziraju dosadašnja dostignuća u razvitku magnetskih lebdećih vlakova (MAGLEV). Kroz povijesni pregled prati se razvitak najpoznatijih današnjih sustava magnetskog lebdenja.

Osim objašnjenja rada i tehničkih značajki svakog sustava, u članku se obrađuju prednosti i nedostaci pojedinih sustava, te prednosti i nedostaci magnetskih lebdećih vlakova u odnosu na konvencionalnu željeznicu.

U radu je dat osvrt na planove budućnosti kao i na sustave koji imaju najveće izglede za komercijalnom, a ne samo eksperimentalnom uporabom.

LITERATURE

[1] **H.G. Raschbichler, L. Miller**: *Superspeed Maglev Systems*, World Congress on Railway Research, Paris, France, November 1994,

[2] **W.J. Mayer:** *Speed Record for the Japanese MLU Superspeed Maglev System*, Eisenbahntechnische Rundschau, September 1994,

[3] **H.G. Raschbichler:** *Die Magnetschnellbahn Transrapid - Ein neues Verkehrssystem für den Personen- und Gütertransport*, ZEV+DET, Glass. Ann. 116(1992), No. 8/9, Berlin,

[4] HSST Development Corporation: *Commercialization of Magnetic Levitation Linear Motorcar*, JETHRO, Tokyo, July 1994,

[5] Hyundai Precision and Industry Co., Ltd: *Reaching for the Limits in Rail Transportation*, July 1993.