International Journal of Modern Engineering Research (IJMER)
www.ijmer.com Vol.3, Issue.2, March-April. 2013 pp-1161-1166 ISSN: 2249-6645

High Speed Trains

Shripad Shashikant Chopade[1], Dr. Pushpendra Kumar Sharma[2]

[1]Shripad shashikant chopade, scholar student of Mechanical Department, Nri-ist Bhopal, India
[2]Dr. Pushpendra kumar sharma, Head & Guide of Mechanical Department, Nri-ist Bhopal, India

Abstract: *When English inventor Richard Trevithick introduced the steam locomotive on 21 February 1804 in Wales, it achieved a speed of 8 km/h (5 mph). In 1815, Englishman George Stephenson built the world's first workable steam locomotive.*

Keywords: *Eurostar, Magnet train, TGV, Tilting tracks, tilting trains.*

I. Introduction

In 1825, he introduced the first passenger train, which steamed along at 25 km/h (16 mph). Today, trains can fly down the tracks at 500 km/h (311 mph). And fly they do, not touching the tracks.

There is no defined speed at which you can call a train a high speed train but trains running at and above150 km/h are called High Speed Trains.

A. The Decline of Rail as a Form of Passenger Transport

Since the automobile has become more widespread with the existence of motorways, cars may reach speeds of up to 75 mph (120 km/h) or thereabouts depending on local laws. Standard mainline railway trains running at 100 mph (160 km/h) have found it difficult to compete with the car, as once journey time to and from the station and waiting for the trains had been calculated, rail travel did no longer offer a significant journey time advantage over the car. In order to attract people to railways ticket prices had to be at the lowest possible, meaning minimal profits. No one would want to build a brand new railway line; the interest payments would crush any company. All this has meant that in the early-mid 20th century new railways were unheard of and some small lines were often closed down because they made a loss.

It seems quite exciting for rail that now today railways are making a come-back. Thousands of miles/km of new railways has been built in the last decade, and new lines are under construction all over the world. Since 1981, over 1000 km (600 miles) of new track has been laid for high speed trains in France.

B. Problems Running On Existing Railways

The primary problem with existing railways is that they can have tight curves. The centrifugal forces on an object going round a bend are the function of the square of velocity, i.e., double the speed, quadruple the centrifugal forces, triple the speed, centrifugal forces increase by nine-fold. Therefore even what might appear mild curves provide problems at speed.

Other key problems are that running on existing railway; the new fast trains have to be scheduled in around the conventional trains. This can be a tricky thing, especially on a busy network; fast trains can easily become stuck behind slow running ones, resulting in delays.

Safety is also a paramount consideration. Although since initial construction 100 years ago the track will have been replaced many times, the foundations of the railways are the same which means after heavy rains for example the track may sag slightly and lose some alignment, a real problem only at high speed. Level crossings also pose a problem.

1. High Speed Lines

To have a high speed rail system, making the high speed trains is really the tip of an iceberg. What really makes systems a success or failure is the railway that they run at. Railways like roads have speed restrictions, and like on roads, often the speed restrictions are below the top speed of the train. Building a fast train is easy, but its building tracks good enough to allow trains to safely and smoothly travel at 160-200 mph or 250-320 km/h, which are also long enough to allow the trains to accelerate up to these speeds (often many miles) and decelerate, is quite difficult.

1.1 Features of a High Speed Railway

i) No level crossings (grade crossings).
ii) Fenced off.
iii) Concrete foundations.
iv) Wide spacing between lines.
v) Curves of radius less than 5 km are avoided and are tilted.
vi) Gradients more than on conventional railway line.
vii) Through stations are constructed with 4 tracks.
viii) Tunnels avoided.

Level crossings are the most common reason for accidents on railways, where road vehicles break down or get stuck on the railway and the train crashes through them

All high speed lines are fenced off. Indeed in the UK all railway lines are fenced off anyway, however on continental Europe many railway lines are easy to get onto. High speed lines are fenced off for obvious reasons, to eliminate the risk of any animal or people wandering onto the railway line.
Foundations for high speed lines are much deeper than conventional railways. Usually a layer of concrete and tarmac is put down (like a road) and then the ballast is put on top. This is to try and stop movements in the ground from affecting the alignment of the railway.

The wide spacing between the lines is important because when two trains pass each other the speed difference can be as much as 600km/h or 370mph. If the two trains are too close together this causes at first a burst of air pressure when they first pass and then a drop in pressure during the coaches. Although this isn't enough to push the trains off the track, repeated stress on the windows may cause fatigue and they may break eventually. So for safety reasons two tracks in each direction are placed further apart than on normal lines.

Gentle curves are key in what high speed lines are about. Tight curves on TGV lines have a radius of about 3 miles or 5 km. Curves are also banked up a lot more than on conventional lines. This is because slow trains will not run on them and it is extremely rare for a TGV to come to a stop because of a signal. The degree of banking is calculated to exactly balance centrifugal forces at running speed.

Perhaps surprisingly greater gradients are allowed on high speed lines than conventional railways. There are two key reasons for this, first of all modern high speed trains are extremely powerful, TGVs generate as much as 12,000hp, steam engines were nowhere near as powerful (about 1,000hp) in the era when conventional railways were built. The second reason is that the faster a train travels the less it will slow down for the same rise in height. This is because as it is going fast it takes less time to climb the hill and so gravity has less time to act to slow the train down.

Generally speaking engineers try and avoid tunnels on high speed lines. This is because when a train enters a tunnel at speed it causes large pressure changes. This can be painful and harmful to passengers' ear drums. A solution was thought to pressure seal trains (as with the TGV). However with very high speed trains (300 km/h), the pressure changes can be so large it can shatter the windows, particularly when two trains pass in opposite directions in a tunnel with a closing speed of 600 km/h in a confined space. However German and Italian high speed lines include tunnels but they have subsequent speed restrictions. As a result the best average speeds along German (200 km/h) and Italian (165 km/h) lines are considerably lower than in France (254 km/h) and Japan (262 km/h), and even a British conventional railway outperforms the Italian high speed line in terms of speed with an average of 180 km/h between London and York.

1.2 Where High Speed Lines Run

It must be emphasized that high speed trains may run on conventional railway but are usually limited to 230 km/h-200 km/h. Most high speed railway services in Europe spend most of their journey on conventional lines, but come together for a fast run on a trunk line.

II. Tilting Trains

We all know that if you are driving in your car and you take a corner at speed you feel centrifugal forces. Well it is no different from trains, if a train takes a corner at speed then centrifugal forces come in. Often train operating companies face a decision for building a high speed railway transport system, i.e., they can either invest money in the train to make it tilt but use existing railway lines, or they invest money in a new railway but don't need to spend money on expensive tilting mechanisms. This is why TGV and bullet trains do not tilt, because they have their own dedicated high speed railway lines where curves are built with very high radii.

It is worth pointing out that the centrifugal force is a function of 'v^2/r' where 'v' is the velocity and 'r' is the radius. This means that if you double the velocity, you quadruple the centrifugal force. Similarly, if you want to triple the velocity but keep the centrifugal force the same, you must increase the radius by a factor of nine. This is why even apparently gentle curves can be much more of a problem with high speeds than one might think, because the force rises with the square of velocity.

2.1 Why Tilting Helps

When sitting on a corner going at speed there are two forces acting on you, gravitational force and the centrifugal force which is accelerating you into the corner. When two forces act, it causes a resultant force. The resultant force will push you into your seat and to the side. However if the train is tilting, then the normal contact force of you on your seat will be the same as the resultant force you are experiencing. This means as far as the passenger is concerned he or she is just being pulled into his or her seat, and he or she is used to that, so no discomfort is felt.

This is true also of aeroplanes, commercial planes tilt a large amount, up to 30 degrees when going around corners in some cases to cater for passenger comfort. As the tilting of the aero plane is to get rid of the problem of centrifugal forces, or more accurately to disguise the centrifugal forces as a part of gravity as far as the passengers are concerned. The only way you know if the aeroplane is tilting is to look out of the window.

Trains that tilt can go up to 25% to 40% faster around curves than conventional trains without upsetting the passengers, and as mentioned before this can significantly increase average speeds and cut journey times.

2.2 Tilting Of Tracks

High speed lines in the UK are heavily banked up on corners, but going in a high speed train, you don't notice it at all. Occasionally when a high speed train comes to a stop because of a red signal or something on a curve you can really notice how much it's slanted. On a stop on a curve put a bottle on the floor and will slide across to the other side.

However there are limitations with tilting tracks. First of all, the banking has to be designed with a specific speed in mind. A banked up track meant for 125 mph trains is going to cause discomfort to passengers in a local 75 mph train, as when a slower train goes round a banked corner it will make passengers feel like they are falling to a side. Of course you could build dedicated high speed lines, but then you would engineer them without tight curves. This limits the extent to which tracks can be banked up. If the track is banked too much for really fast trains, then if any train comes to a stop on the curve due to a red signal the slant will cause discomfort to passengers. Also arranging for the overhead pantograph to make proper contact with the wire above a banked curve would be difficult.

Clearly trains themselves need to tilt. Then you get the double benefit of tilted track and tilting train, and the train can tilt to exactly suit the speed it is going at.

2.3 Tilting Of Trains

Carriages have tilting mechanisms. Obviously the bogies cannot tilt because they ride on the track and must follow the path of the track. So the coaches have to tilt on the bogies. The way they do this is simple, the bogie acts a fulcrum in the centre and it is free to tilt on either side. Then pistons control how much the coach tilts. The pistons are controlled by a small computer, which uses a spirit level. The spirit level is used to check the closeness to horizontal, remember, i.e. at right angles to the resultant force acting. Normally this force is gravity, but when going round a corner the resultant is a combination of gravity and centrifugal forces. This means the spirit level indicates it is no longer horizontal, so the computer adjusts the pistons until horizontal is read. Again this will not be horizontal to the ground, but as far as anyone on the train is concerned it will be horizontal, keeping the passengers happy.

In the early days it was tried to use inertial force to let the trains tilt. i.e., they would have no mechanism to make them tilt but the carriages would have a low centre of gravity so centrifugal forces on the carriage would cause them to tilt. This proved unsuccessful.

III. MAGLEV (MAGNETICALLY LEVITATED TRAINS)

The principle of a Magnet train is that it floats on a magnetic field and is propelled by a linear induction motor. They follow guidance tracks with magnets. These trains are often referred to as Magnetically Levitated trains which are abbreviated to Maglev. Although maglev don't use steel wheel on steel rail usually associated with trains, the dictionary definition of a train is a long line of vehicles traveling in the same direction - it is a train.

3.1 Working Principle

A maglev train floats about 10mm above the guide ways on a magnetic field. It is propelled by the guide way itself rather than an onboard engine by changing magnetic fields. Once the train is pulled into the next section the magnetism switches so that the train is pulled on again. The Electro-magnets run the length of the guide way.

3.2 Advantages of Maglev

Well it sounds high-tech, a floating train; they do offer certain benefits over conventional steel rail on steel wheel railways. The primary advantage is maintenance. Because the train floats along there is no contact with the ground and therefore no need for any moving parts. As a result there are no components that would wear out. This means in theory trains and track would need no maintenance at all. The second advantage is that because maglev trains float, there is no friction. Note that there will still be air resistance. A third advantage is less noise, because there are no wheels running along there is no wheel noise. However noise due to air disturbance still occurs. The final advantage is speed, as a result of the three previous listed it is more viable for maglev trains to travel extremely fast, i.e., 500 km/h or 300 mph. Although this is possible with conventional rail it is not economically viable. Another advantage is that the guide way can be made a lot thicker in places, e.g., after stations and going uphill, which would mean a maglev could get up to 300 km/h (186 mph) in only 5 km where currently takes 18 km. Also greater gradients would be applicable.

3.3 Disadvantages with Maglev

There are several disadvantages with maglev trains. Maglev guide paths are bound to be more costly than conventional steel railways. The other main disadvantage is incompatibility with existing infrastructure. For example if a high speed line between two cities is built, then high speed trains can serve both cities but more importantly they can serve other nearby cities by running on normal railways that branch off the high speed line. The high speed trains could go for a fast run on the high speed line, and then come off it for the rest of the journey. Maglev trains wouldn't be able to do that; they would be limited to where maglev lines run. This would mean it would be very difficult to make construction of maglev lines commercially viable unless there were two very large destinations being connected. Of the 5000 km that TGV trains serve in France, only about 1200 km is high speed line, meaning 75% of TGV services run on existing track. The fact that a maglev train will not be able to continue beyond its track may seriously hinder its usefulness.

3.4 Effect on Environment

In terms of energy consumption maglev trains are slightly better off than conventional trains. This is because there is no wheel-on-rail friction. That said, the vast majority of resistive force at high speed is air resistance (often amounting to several tons), which means the energy efficiency of a maglev is only slightly better than a conventional train.

German engineers claim also that a maglev guide way takes up less room and because greater gradients are acceptable there is not so much cuttings and embankments meaning a new guide way would be less disruptive to the countryside than a new high speed conventional railway.

IV. Important High Speed Trains

4.1 The Pendonlini

Class	ETR 450	ETR 500
Introduced	1987	1996
Commercial Speed	250 km/h (155 mph)	300 km/h (186 mph)
Best Average Speed	164.5 km/h (102.4 mph)	N/A

Table 4.1: ITALIAN PENDOLINIS

4.2 The Advanced Passenger Train

Top Planned Commercial Speed	150 mph (240km/h)
Speed Records	APT_E 152 mph (244km/h) 1975 APT_P 162 mph (260km/h) 1979

Table 4.2: THE ADVANCED PASSENGER TRAIN

4.3 The Eurostar

Top Commercial Speed	186 mph, 300km/h
Top speed in England	100 mph 160km/h
Top speed in the Channel Tunnel	100 mph 160km/h

Table 4.3: EUROSTAR

The Eurostar was Europe's first international train, designed to take advantage of the Channel Tunnel, to provide a high speed rail service between London and the UK to destinations in Continental Europe.

4.4 Le Train À Grande Vitesse (TGV)

Name	TGV Paris Sud-Est	TGV At antique	AVE	TGV Reseau	Eurostar	TGV Thalys
Introduced	1981	1989	1991	1993	1994	1996
Top Average Speed	135mph	Unknown	132mph 209km/h	158mph (254.3km/h)	N/a	132mph
Operating Speed	168mph 270 km/h	186mph 300km/h	186mph 300km/h	186mph 300km/h	186mph 300km/h	186mph 300km/h
Design	168mph	186mph	186mph	200mph	200mph	200mph

Speed	270 km/h	300km/h	300km/h	320km/h	320km/h	320km/h
Speed Record	236mph 380 km/h	320mph 515km/h	N/A	N/A	N/A	N/A
Max speed on normal rails	138mph 220km/h	138mph 220km/h	No running	138mph 220km/h	100mph 160km/h	unknown

TABLE 4.4: DIFFERENT TYPES OF TGV

The name "Train à Grande Vitesse" translated into English means high speed train, not really very imaginative, but seeing as it is French it tends to get away with it. There is no single TGV as such; in fact there are many generations of TGV, each generation consisting many trains. The TGV project started in the 1960s where SNCF realized that if it was to compete against the ever growing automobile and air transport it had to offer seriously better speeds.

V. Advantages of High Speed Trains

a) Reduced CO2 Emission

The USA has the highest CO2 emission rates in the whole world. The rate of car ownership is slightly higher in the USA. People must use their cars very much more in the USA accounting for the extra emissions because, the USA has very little by the way of railways, both high speed and local. It would seem reasonable to conclude that the more trains you have, the lower your country's CO2 emissions.

b) Huge capacity

High speed railways have by far the highest capacity per unit land they use. A high speed rail needs just a double track railway, one rail for trains in each direction. These have a capacity for 16 trains per hour, each train with a capacity of 800 passengers. This means a high speed rail has a maximum capacity of 12,800 passengers per hour, which clearly is enough to satisfy the highest of demand; only one railway line is needed. This is unlike motorways which take up a very large amount of space and often cannot satisfy demand fully at peak times.

c) Reduced traffic

Imagine you have two cities about 500km or 312miles apart, by car, the journey time will be about 6 hours. The motorways will be jammed full. If you can provide a new rail service of 300km/h 186mph between two cities the journey time by rail will be about 2 hours. Provided the rail service is well priced, very few people are likely to drive any more between the cities, causing a massive decrease in traffic. Of course with a decrease in traffic, pollution decreases too.

d) Energy efficiency

The energy resources are limited. The train offers per passenger energy efficiency that no other form of transport can achieve. The reason is because of steel wheels on steel rails The hard smooth surfaces provide very little friction. Also because the wheels are held by steel ball bearings, friction is very low even at high speed. Air resistance of a train is not really a problem because it is thin and long. On the other hand aircraft must burn huge amounts of fuel even to move at all, and in flight the engines have to continue to burn just to keep the plane in the sky. Once a train is moving, even if the engines are switched off, the train doesn't even decelerate noticeably, even at very high speeds. Cars, as everyone knows, are by far the least efficient form of transport.

e) Reduced pollution

Because of their efficiency, the pollution that a train makes is very low, and if the electricity being used for the train is generated by a green source then there may well be no pollution at all as a result of running the train. Reduced traffic also reduces pollution, no more cars pumping out gases in huge amounts, and of course compared to aeroplanes which need to burn fuel at an astonishing rate just to get thrust. In fact, it has been calculated that a Eurostar train with a capacity of 800 causes pollution level through power stations about equivalent to 20 cars.

f) Speed

300 km/h is very fast. That is the speed at which these trains fly along. No time is wasted in getting people to their destinations. There is no worry about waiting in traffic, or having a long stressful drive. Also it means that flying can be avoided, which is particularly welcome for the more ecological people.

g) Convenience

While airports are often out of town and hard to access, railway stations are usually located in the heart of the city. Also with some services you can just buy a ticket and get straight on the train, with no advanced booking required. Aircraft have drawbacks such as long check-in times and constant moving around.

h) Safety

What is perhaps not known about is that high speed trains are in fact the safest form of transport. High speed trains are perhaps surprisingly safer than normal trains. Most use very advanced computer signaling systems meaning risk of collision is very low, and apart from that there is not a lot that can go wrong. France had a train going at 320 mph (512 km/h), which shows that dangerous, experimental speeds are a long way off commercial everyday speeds.

i) Comfort

With the possible exception of cruise ships trains are the most comfortable form of transport. Even at these very high speeds the train remains about as smooth as an aircraft, and of course very much quieter. Also there are no limitations, the seats are not cramped like in an aircraft, and unlike in a car you can get up, walk around, or buy a snack from the buffet car.

VI. Drawbacks of High Speed Rail

a) Social drawbacks (externalities)

The only real externality is the fact that in order to build high speed rail lines the country side has to be sacrificed. This particular externality applies to all forms of transport however (with the possible exception of water). Although high speed rail lines do not occupy a large amount of room, the fact that they have to be straight and level usually involves large amounts of embankments and cuttings causing considerable disruption to the countryside.

b) Economic drawbacks

The primary objection is always cost. High speed railways are very expensive. To build the high speed link in the UK between London and the Channel tunnel for 300km/h Eurostars it is costing the Government and private companies £3 billion (US $4.8 billion). This railway is just 68 miles long (108 km). This is perhaps an extreme example, high speed railways typically are not so expensive but difficult geography (rolling hills) and high population density of the area has pushed up the cost.

c) Cost-effectiveness on the basis of pollution control

High initial costs often mean public money has to be used because the private sector is usually unwilling to engage in such large projects. As a result many would argue that the money used to build such rail systems would be more effectively spent in other projects if the primary objectives were to reduce traffic congestion/pollution.

d) Limitations of high speed rail

High speed rail is only applicable to inter-city services in high density corridors (having said that connecting trains can deliver people door to door). This means that, in order to work effectively, high speed rail must be backed up by a decent urban/light rail transit system, as found in Europe and Japan. Such systems are rarer.

e) Limitations of geography

High speed railway lines need to be as straight and level as possible. Therefore often the railways are carried over dips and hills in the countryside by embankments, viaducts, cuttings and tunnels. (Tunnels are sometimes unsuitable due to wind turbulence problems.) However these greatly increase the cost of the railway and of course, if the landscape is mountainous then it becomes very difficult to build it straight and leveled. Naturally, railways cannot be built over water for long distances.

VII. Conclusion

Although there have been derailments, in the almost two decades of daily operation, there has been no casualties. While the very high speed trains like the TGV could be regarded as the Rolls Royce of trains, tilting trains could be thought of as the cheap and cheerful mini metro. The price differential is fairly similar too; it costs about 20 times more per unit distance to build a dedicated high speed line than it does to upgrade existing lines for tilting trains. This is what makes tilting trains extremely attractive. However there are disadvantages. 140 mph or 230 km/h is about as fast as trains go when not on dedicated lines. And then they have to be fitted in with slower moving traffic. With rail travel growing all over Europe, the problems of railways reaching saturation point has forced new lines to be build. This is why despite the success of the Italian Pendolini; a new high speed line with 300 km/h trains is being built, because existing lines are at saturation point. Most of the high speed train functions are controlled digitally, true to being the vehicle of the digital age.

VIII. Acknowledgment

The author wishes to acknowledge the Project Guide Dr. Pushpendra Kumar Sharma, Head of Department Nri-ist Bhopal, India, for their continual guidance.

References

[1] Science and Technology Review, June 1998.
[2] Hood, Christopher P, Shinkansen- From Bullet Train to Symbol of Modern Japan, Routledge, 2006.
[3] Moon, Francis C, Superconducting Levitation Applications to Bearings and Magnetic Transportation, Wiley-VCH, 1994.
[4] En.wikipedia.org
[5] www.o-keating.com