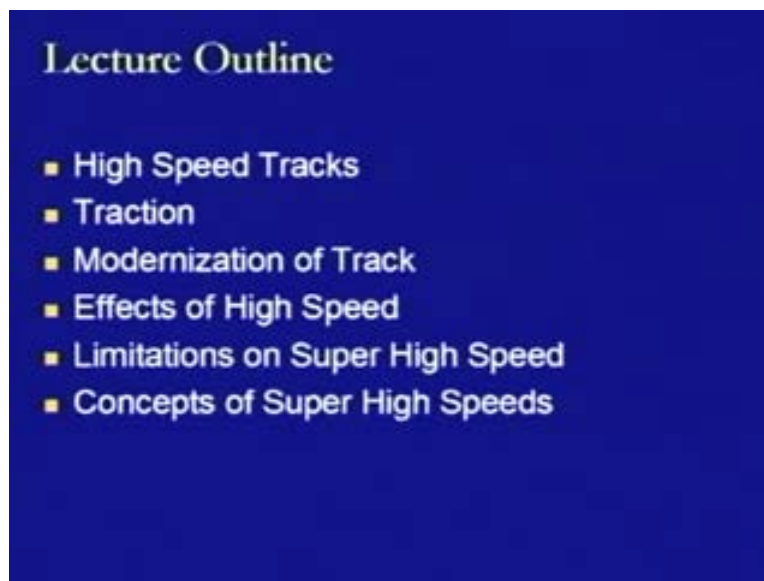


**Transportation Engineering - II**  
**Dr. Rajat Rastogi**  
**Department of Civil Engineering**  
**Indian Institute of Technology - Roorkee**

**Lecture - 26**  
**High Speed Tracks**

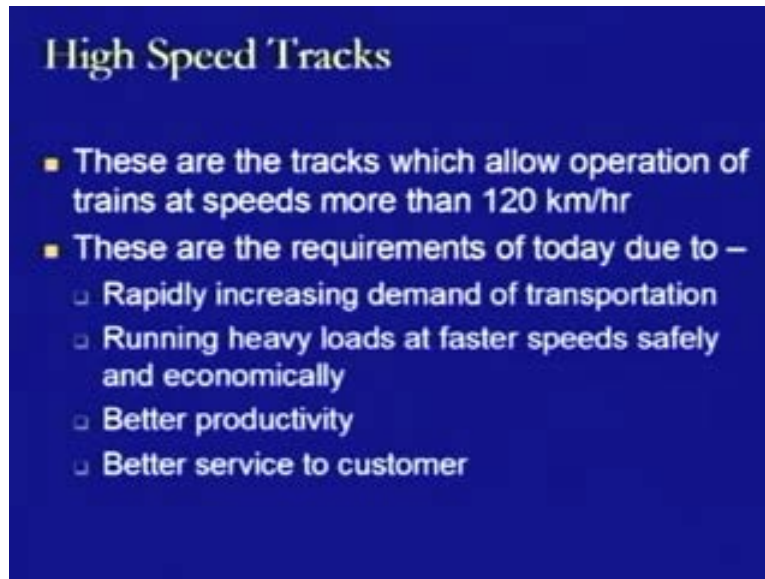
Dear students, I welcome you back to the lecture series of course material on Transportation Engineering – II. This is the last and final lecture as far as the railway engineering is concerned and this is devoted to the high speed tracks. So far what we have seen is the case of conventional tracks, where the trains can move up to a speed of something like 120 kilometers per hour. In today's lecture, we will try to look at the requirements of any high speed track, where the trains are supposed to move on speeds higher than 120 kilometers per hour or can even move at a speed of something like 250 to 300 kilometers per hour, in general.

(Refer Slide Time: 1:29)



We will be also looking at different limitations which arises and limitise the limit on the speed of the trains on the track and in this regard, this lecture is being outlined with high speed tracks, the traction, the modernization of track, the effects of high speed and the limitations on super high speed and further certain concepts of super high speeds.

(Refer Slide Time: 1:48)



So, we are starting with the high speed tracks. These are the tracks which allow operation of trains at speeds more than 120 kilometers per hour. These are the requirements of today, because there is a rapidly increasing demand of transportation, the running of heavy loads at faster speeds safely and economically is another requirement between the two major terminal stations. It has also associated with better productivity and it will be possible to provide better services to customer, if they can be transported or the freights can be moved at higher speed.

(Refer Slide Time: 2:36)



The high speed trains can be classified in two categories as the high speed tracks where the speeds are over 120 kilometers per hour and are up to 250 kilometers per hour and the super high speed tracks where the speeds are above 250 kilometers per hour.

(Refer Slide Time: 2:58)



The development of high speed and super high speed tracks requires the high speed tracks. In the case of high speed tracks, it is the modified traction like diesel and electric

traction instead of steam traction and modernization of present track to higher standards. In the case of super high speed tracks, we require advanced traction efforts and track modernization. So, that is what we see is in terms of, in general it is related to traction and it is related to the modernization of the track.

(Refer Slide Time: 3:44)



In the case of high speed tracks, the development consists of the modernization of track and the use of better designed rolling stock, adopting superior type of traction and better telecommunication and signaling arrangements and modern techniques of maintenances. These are the things which needs to be given due consideration if we are interested in developing high speed tracks.

(Refer Slide Time: 4:14)



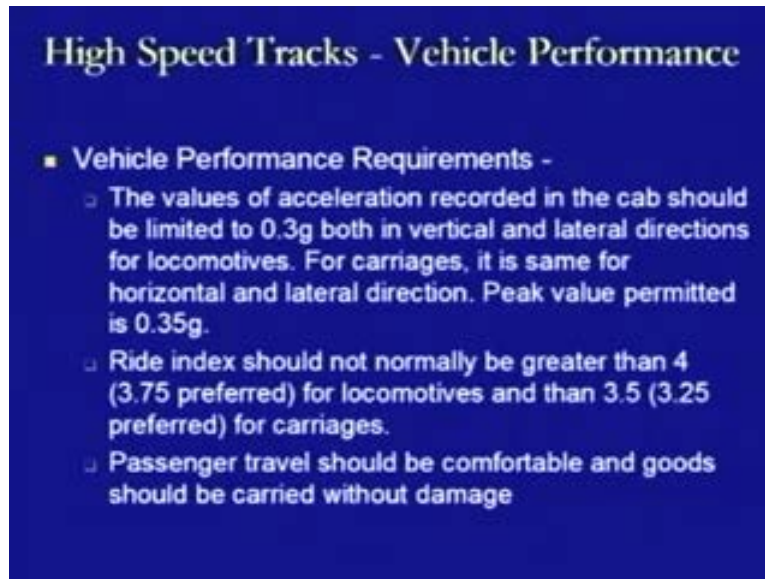
**High Speed Tracks – Vehicle Performance**

- **Vehicle Performance Requirements -**
  - At locations in the track where defects occur, the variations in vertical and lateral loading should not reach a condition where the wheels can derail by mounting
  - The variations in vertical and lateral loads should not reach a condition in which derailment can occur by distortion to track
  - In case of diesel and electric locomotives, lateral force lasting for more than 2 meters should not normally exceed 40 percent of the axle loads plus 2 tons.

Starting with these factors, first of all we are looking at the vehicle performance with respect to the high speed tracks. The vehicle performance requirements are that at locations in the track where defects occur, the variations in the vertical and lateral loading should not reach a condition where the vehicle can derail by mounting. That is the one vehicle performance requirement with respect to the defects. It is related to the vertical movements, variation in the vertical and lateral loading conditions, where the derailment should not be there due to movement or due to mounting of the wheels over the rails. The variations in vertical and lateral loads should not reach a condition in which derailment can occur by distortion to track. This is another condition which needs to be satisfied.

In case of the diesel and electric locomotives, the lateral force lasting for more than 2 meters should not normally exceed 40% of the axle loads plus 2 tons. That is another limiting value which is there with respect to the lateral force which can work for more than 2 meters distance that is for continuation of 2 meters distance movement. If there is a lateral force which is exceeding 40% of the actual load plus 2 tons, then that is going to be a dangerous condition and should not happen.

(Refer Slide Time: 5:49)

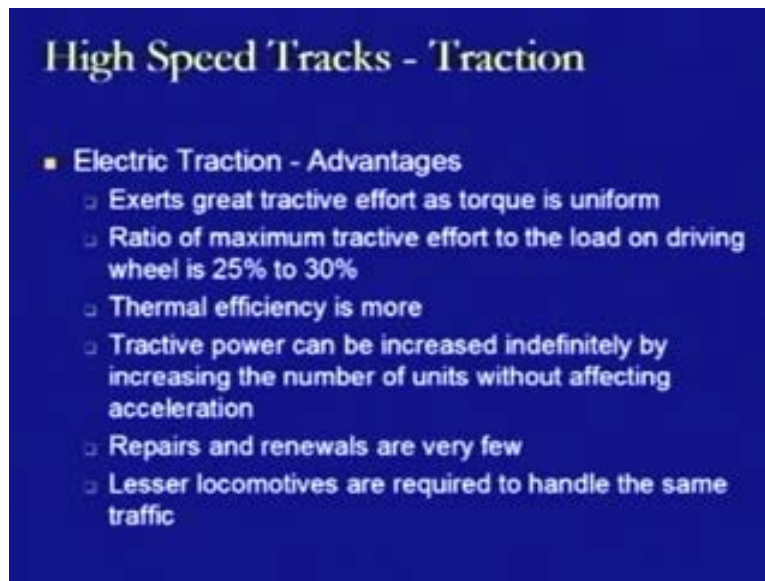


### High Speed Tracks - Vehicle Performance

- Vehicle Performance Requirements -
  - The values of acceleration recorded in the cab should be limited to 0.3g both in vertical and lateral directions for locomotives. For carriages, it is same for horizontal and lateral direction. Peak value permitted is 0.35g.
  - Ride index should not normally be greater than 4 (3.75 preferred) for locomotives and than 3.5 (3.25 preferred) for carriages.
  - Passenger travel should be comfortable and goods should be carried without damage

Further, the value of acceleration recorded in the cab should be limited to 0.3 g, both in vertical and lateral directions for locomotives. For carriages, it is same for horizontal and lateral direction and the peak value permitted is 0.35 g. That is the amount of acceleration which can be there in the vertical and lateral directions. The ride index should not normally be greater than 4 and 3.75 is the preferred value for locomotives and it should not be greater than 3.5 with 3.25 as a preferred value for carriages and the passenger travel should be comfortable and goods should be carried without damage.

(Refer Slide Time: 6:37)



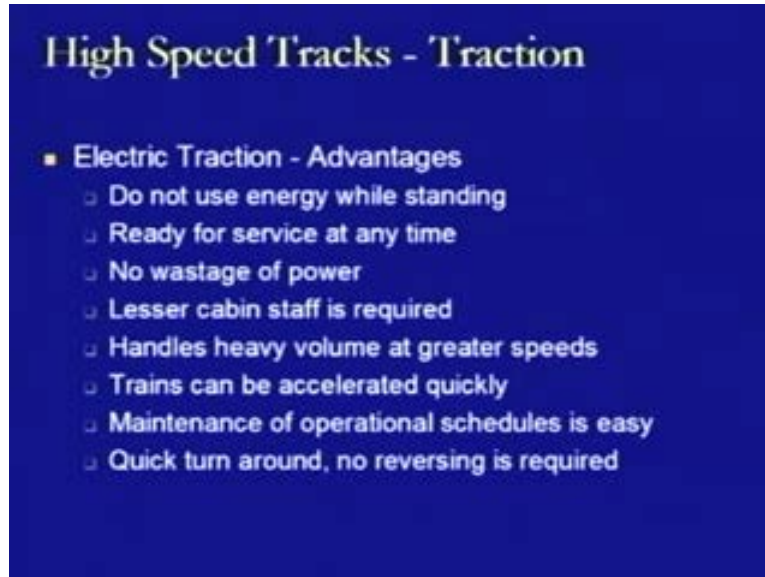
Now, looking at the traction required for the high speed tracks, the main advantageous traction effort is the electric traction and there are certain advantages of this electric traction over the other type of traction that is the diesel traction and the steam traction. So, we look at those advantages. The electric traction exerts great tractive effort as torque remains uniform. That is one of the advantages, because of the uniformity in torque there is more of the tractive effort available. The ratio of maximum tractive effort to the load on driving wheel is 25% to 30% means there is lesser amount of resistance which may be there on the driving wheels. The thermal efficiency is more in the case of electric traction. That is another condition, where the transformation of energy is associated with and the tractive power can be increased indefinitely by increasing the number of units without affecting acceleration.

This is another advantageous condition in this case, whereas in the diesel electric locomotives, diesel locomotives if we have to improve upon the tractive power, then more of the locomotives need to be attached. But, that is not the case in electric traction condition. Only simply the units have to be placed on the same bogie combination. The repairs and renewals are very few in the electric traction. There are lesser locomotives required to handle the same traffic, because they have a higher tractive effort and



therefore, they can move more of the loads as compared to the other locomotives of different categories.

(Refer Slide Time: 8:30)

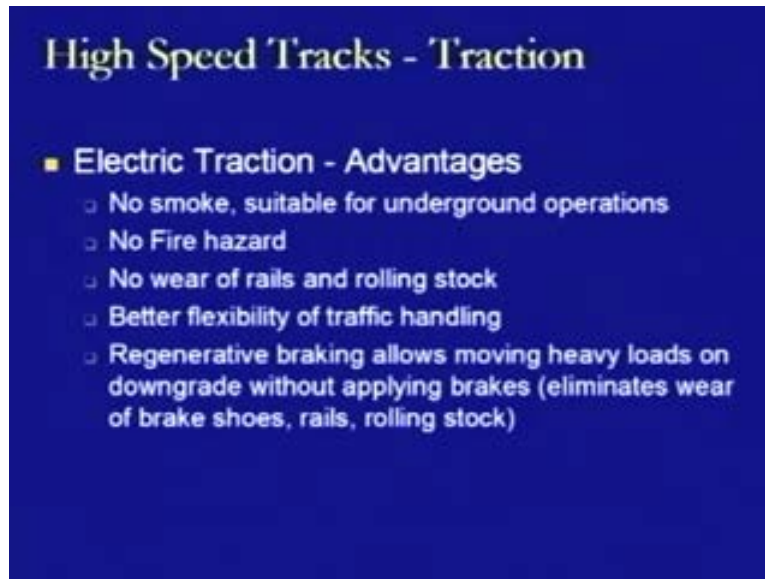


Further, they do not use energy while standing means they do not have to be kept in running position while in idle condition which is the case in the case for diesel engines which needs to be kept ON, even if they are being not in use, so that they can be used readily. They are ready for service at any time, because of this reason only. There is no wastage of power in this sense, because they do not have to be kept in idle condition in running condition that is where the wastage of power will come in. There is lesser cabin staff required in the case of electric traction as compared to the other type of driven locomotives.

They can handle heavy volumes at greater speeds; that is another advantageous condition. The trains can be accelerated quickly. Maintenance of operational schedules is easy and there is a quick turn around, because there is no reversing required in the case of electric traction locomotives.

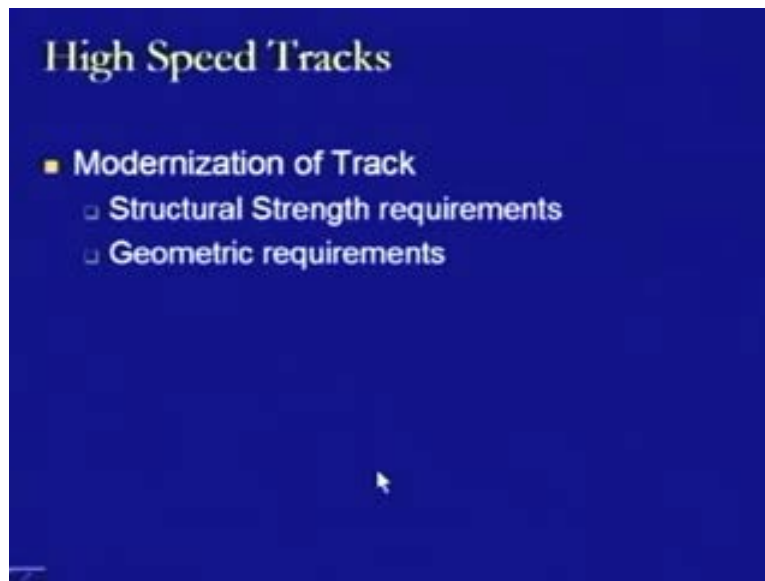


(Refer Slide Time: 9:44)



Further, there is no smoke and they are therefore, suitable for underground operations. There is no fire hazard. There is no wear of rails and rolling stock in the case of electric traction. There is a better flexibility of traffic handling, because they have a higher tractive effort available and so, if more traffic is to be handled, then the more electric tractive power units can be installed on the same locomotive. The regenerative braking allows moving heavy loads on downgrades without applying brakes. That is by this we eliminate the wear of brake shoes, rails, rolling stock, etc. So, that is one of another advantageous condition of electric traction.

(Refer Slide Time: 10:42)



So, we come to another aspect of the high speed tracks that is the modernization of track. We have seen that there are two aspects which need to be considered. One is related with the traction and another one is related to the modernization of track. Now, within the modernization of track, we have different requirements. Out of those, one requirement is of structural strength requirement. Then, there is geometric requirement.

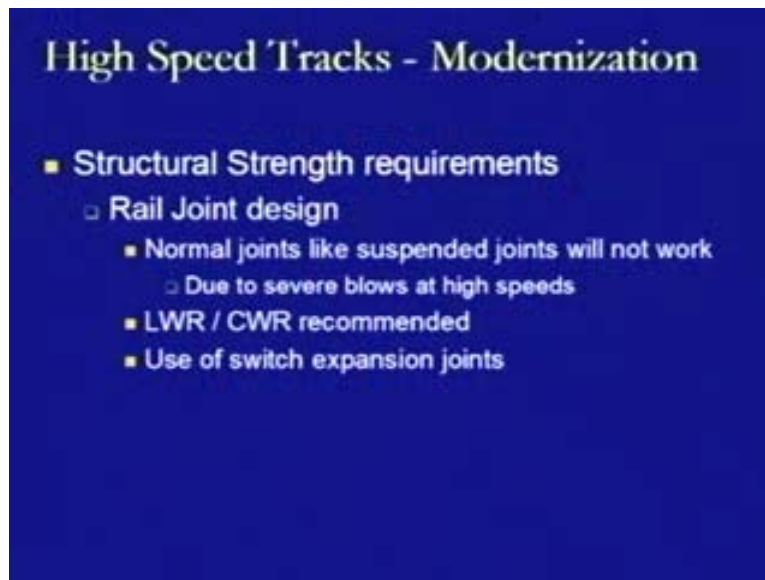
(Refer Slide Time: 11:09)



So, we will be looking at both of these types of requirements one by one and things which need to be taken care of within those structural or geometric requirements. In the case of structural strength requirements, it is related to the rail section where a heavier rail section should be used where with the minimum value of 52 kg per meter. We have already seen this type of rail section, we have 52 kg per meter or 60 kg per meter rail sections. Then, they should be wear resistant rails means we should go for the 90 UTS rail sections which have higher resistance to the wear as well as the hardness number is much high as compared to the normal conventional 72 kg per mm square UTS rail sections.

Improving strength, stiffness and durability is another important thing. That is whatever are the ways by which we can improve upon the strength, stiffness and durability of the sections, then that need to be done for the rail sections.

(Refer Slide Time: 12:21)



Then, further in the case of within the structural strength requirements, another thing is related to the joints which are provided within the rail sections. Whatever rail sections we are using we have to look at, the normal joints like the suspended joints will not work in the case of high speed track, because of the impact which will be produced by the higher

speed at the joint and therefore, there will be **backing** action or hogging action which will be taking place at the end of the rail sections or the joints. So, that is why what is important is that we have to look at the long valid rails or continuous valid rails and these are the two things which are recommended and when we use these, then we can go for the switch expansion joints. So, that is the thing which are recommended as far as the rail joint is concerned, because if we go for LWR or CWR, we will be reducing the location where the point of weaknesses will be there.

(Refer Slide Time: 13:23)



Then, within the structural strength requirements, the other components which needs to be seen is the sleeper, where the use of timber, steel and concrete sleepers with elastic fastenings that is one of the possibilities which can be done. Then, in the case of this sleeper, then we have CST - 9 to CST -13 sleepers, which are provided with special fastenings, so that they can be retained within place without any loosening effect of the sleeper with respect to rail and their connectivity due to the higher speeds at which the trains will be rolling, the stock will be moving and they should be ideally suited as concrete sleepers, because they have a greater weight which is something like 3 to 4 times more than the weight of the other type of the sleepers and at the same time, because of their heavier sections being used, they have higher lateral, longitudinal and vertical

stability. So, that is why the concrete sleepers are most suitable for the high speed tracks as compared to the other type of the sleepers.

Then, high sleeper density is required, so as to have a better stress distribution and greater resistance to deformation, because due to the high speeds, the amount of stress which will be transferred from the top to the bottom is more, therefore higher sleeper density may be taken up and this is minimum and plus 7 for group A line or group B line on the broad gauge track or it may transform into 1660 sleepers per kilometer length of track in group A condition and 1540 per kilometer length of track in the case of group B condition. So, it is more than what we have been using previously for the normal conventional tracks.

(Refer Slide Time: 15:28)



Similarly, for another component that is ballast, certain requirements like adequate ballast below sleepers and at crib and shoulders with LWR or CWR tracks that is the one thing we are required to provide more lateral stability to the track and that is how you can do it. Then, the minimum cushion is 250 mm, whereas the preferable cushion is 300 mm under the sleeper and this is already we have seen when we have discussed about the ballast and we have discussed about the specification of permanent ways. Then, 250 mm ballast plus 150 mm sub-ballast with higher sleeper density is another way by which we can improve

upon the strength of the ballast section and dispersal of the loads or the stresses which are transferred from the top to the bottom that is the formation level.

The shoulder width on the straight and inside of the curve should be minimum 350 mm, whereas the shoulder width on outside of the curve should be minimum 500 mm and that is the values which are desired and should be provided as far as the ballast overall cushion is concerned.

(Refer Slide Time: 16:47)



Then, there are some requirements related to the fastenings. We have already discussed about the rail fastenings, where the elastic fastenings were also discussed and in the case of elastic fastenings, we should go for the use of things like Pandrol clips IRN 202 or 304 clips or lock spike or similar sort of the things which we have discussed already. They are supposed to be used and then, the overall track assembly should work as an integrated type of assembly with atleast LWR track if not the CWR track.

(Refer Slide Time: 17:43)



Then, further there are some requirements related to the formation level, the provision of topping layer with or without water proofing membrane that is one thing as far as the formation level is concerned. Then, provision of sub-bullah piles at the end of the sleepers, so that they remain intact and the amount of the material is not changing its place with reorientation and sucking action of the high speed tracks and the cement grouting of ballast packets as well as the formation that is another thing, so that the material remains fixed to the formation and it is not removed, because of the sort of vacuum or suction effect of the high speed trains.

Then, lime treatment of formation like in terms of may be lime piles or may be in terms of the grouting of the formation level by lime and provision of sub-bank or flattening of slopes, so that the chances or failures of **embankments**, they are reduced and the increase in depth of ballast or sleeper density that is another thing, so that whatever the loads are coming are lower than the load bearing capacity of the formation level. So, these were some of the requirements which are related to the structural strengths.



(Refer Slide Time: 19:09)



Then, some requirements are also related with the points and crossings, the locations from where the change in the direction of the train is allowed. As we have discussed when we discussed about these things in one of the lectures, then what we require is the crossings with the higher numbers and the minimum value in such cases is 1 in 16 and the preferable is 1 in 20 and even 1 in 24 and similar curvature for the various ..... rails need to be provided. There should not be a variation, which otherwise may cause derailment or over turning or over running of the rails by the wheels.

The high cant deficiency in provision of super elevation is another important thing at these locations, because of the higher speeds we have to look at the high cant efficiency, because the same track may also be used by the conventional types of trains, where the speeds are not more than 120 kilometers per hour and the manganese cast steel rail for crossing and curved switches should be used. As far as their strength is concerned, that are better and that is why they should be used at these locations.

(Refer Slide Time: 20:23)

## High Speed Tracks - Modernization

- Geometric Requirements
  - Gauge of track
    - BG is recommended
  - Alignment
    - Flat curves, gentle gradients, adequate cant deficiency

Now, we come to another requirement that is the geometric requirement. In the case of geometric requirement, the first thing is related to the gauge of the track, where the broad gauge is recommended. In the case of alignment, alignment should have flat curves, gentle gradients and adequate cant deficiency. Then only, the movement of the trains over the different type of alignments that is the horizontal alignment or the vertical alignment will remain in safe condition.

(Refer Slide Time: 20:58)

## High Speed Tracks - Modernization

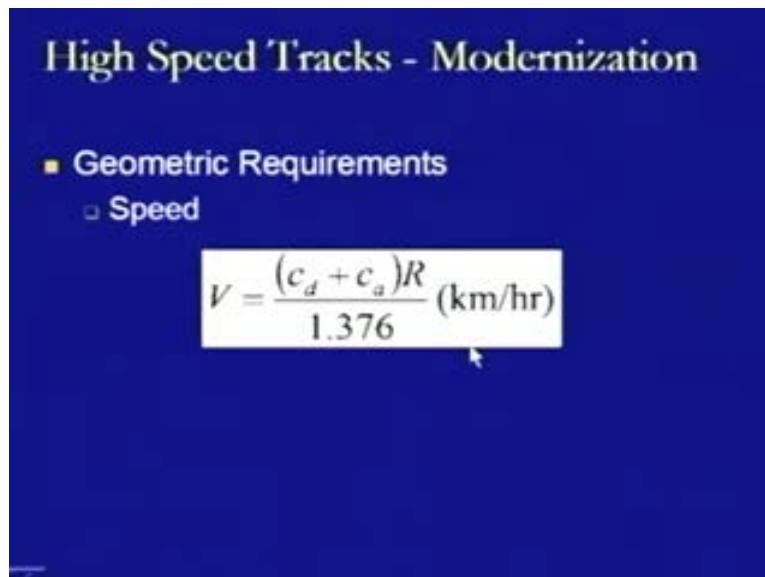
- Geometric Requirements

Max Per. Speed Km/hr	Degree of curve	Radius in m	Equi. cant (cm)	Proposed cant (cm)	Cant deficiency (cm)	Length of transition curve (m)
160	$\frac{1}{2}$	3492	10	4	6	48.5
160	$\frac{3}{4}$	2328	15	6	9	73
160	1	1746	20	10	10	120
160	$1\frac{1}{4}$	1395	25	15	10	180

Then, further there are certain values which have been given here like we are talking about the maximum permissible speed in kilometers per hour, the degree of curve, the radius in meters, equilibrium cant in centimeters, the proposed cant in centimeters, the cant deficiency allowed in centimeters and the length of transition curve in meters for the high speed tracks. Now, for the maximum speed of 160 kilometer per hour, what we see is that there is degree of curve as 1 by 2, then the radius in meter is 3492, 10 centimeters as equilibrium cant, proposed cant as 4 centimeters, cant deficiency as 6 centimeters and 48.5 meter as length of the transition curve.

But, in the same track, if the degree of curve is increased to 3 by 4, then the values changes as 2328 meters is the radius, 15 centimeters as the equilibrium cant, proposed cant as 6 centimeters, cant deficiency as 9 centimeters and the length of transition curve is 73 meters. Further, similarly when the value is further increased to 1 as degree of curve, then there is further reduction in the radius, whereas the rest of the value increases to as high as the length of the transition curve changes from 73 meters to 120 meters. So, this is, continuously it is being shown in the same form for the same speed of 160 kilometers per hour. The effect of change in degree of curve is being shown.

(Refer Slide Time: 22:41)



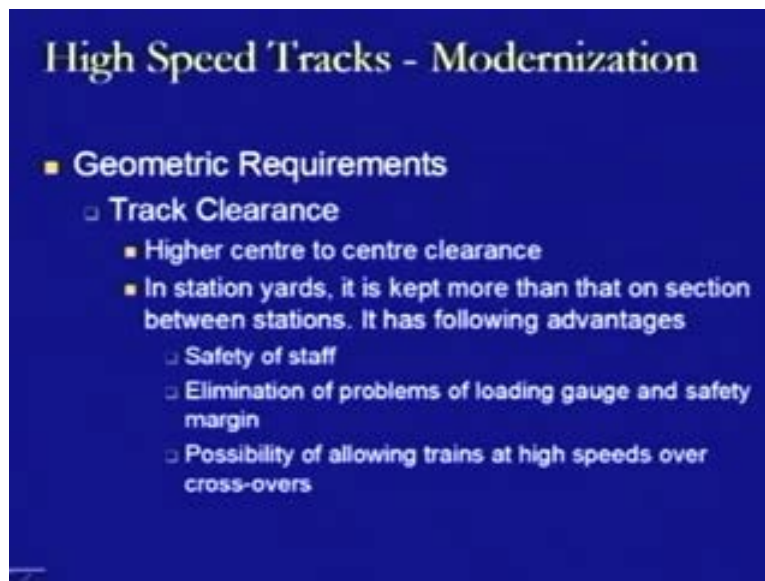
**High Speed Tracks - Modernization**

- **Geometric Requirements**
  - **Speed**

$$V = \frac{(c_d + c_a)R}{1.376} \text{ (km/hr)}$$

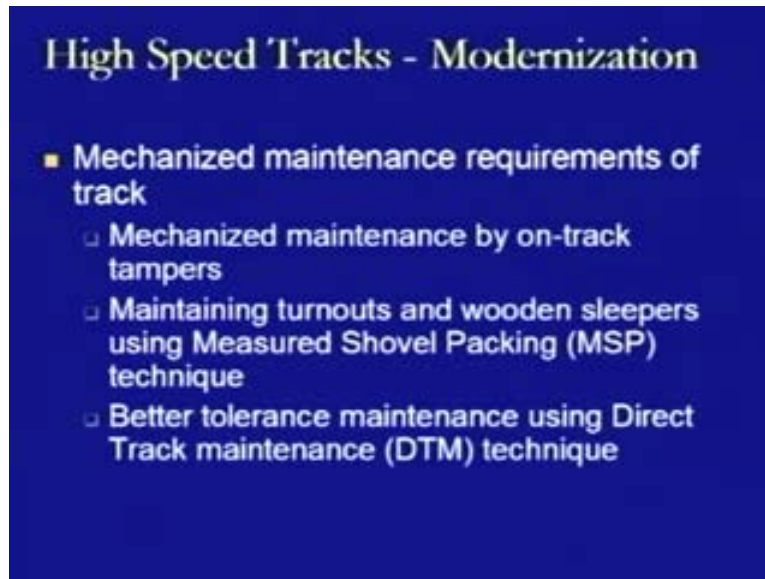
Then, in the case of the speed, the speed is computed by the formula as  $V$  is equals to  $C_d$  plus  $C_a$  multiplied by  $R$  divided by 1.376 and here the speed will come in kilometers per hour, where  $R$  is the radius of the curve and  $C_a$  is the actual cant being provided or super elevation being provided and  $C_d$  is the cant efficiency and this is the same formula which we have seen previously when we discussed about the geometric standards.

(Refer Slide Time: 23:18)



Then, there are certain track clearances which needs to be provided, which we have again discussed when we have talked about the geometrics that are different types of track clearances and widenings. The higher centre to centre clearance is required between the tracks. In station yards it is kept more than that on section between stations. It has following advantages. It helps in maintaining the safety of the staff who is working along the track. It eliminates the problems of loading gauge and safety margins and there is a possibility of allowing the trains at high speeds over cross overs.

(Refer Slide Time: 23:58)



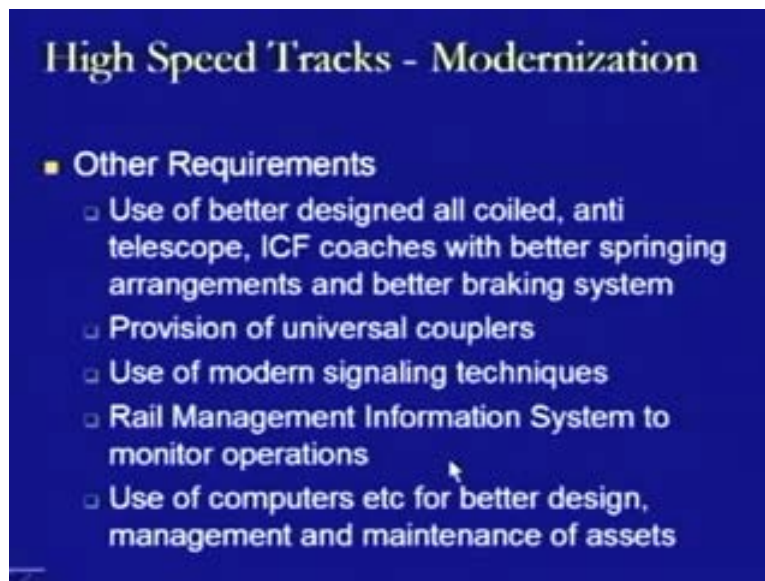
Then, mechanized maintenance requirements of the track are there. The mechanized maintenance by on track tampers, there are maintaining turnouts and wooden sleepers using measured shovel packing technique, better tolerance maintenance using direct track maintenance technique, these are the different ways by which the maintenance can be carried out.

(Refer Slide Time: 24:18)



Mechanized maintenance requirements of track, where we can also use ultrasonic rail flaw detector to minimize incidence rail fractures that is the non-destructive way of finding out the defects. The checking of versines and curves and realigning as per the related directions, we have discussed versines and the curves when we discussed horizontal curves.

(Refer Slide Time: 24:47)

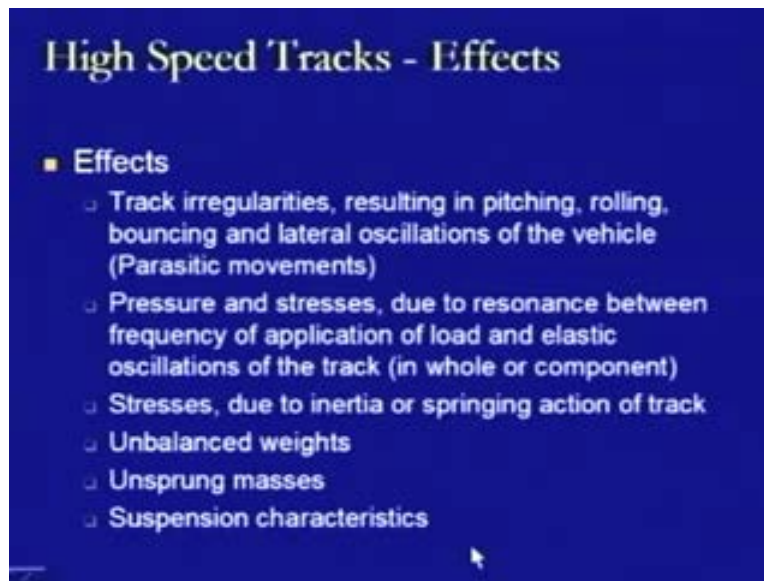


Then, other requirement, the use of better designed all coiled anti telescope, ICF coaches with better springing arrangements and better braking system, provision of universal couplers and use of modern signaling techniques are the different other requirements and then, another aspect is the management information system for rails and this is the way by which we can monitor the overall operations of the trains over the tracks. The use of computers for better designed management and maintenance of assets is just generally it is a part of rail management information system only. So, this is all about the various requirements of any high speed tracks.

Now, we will be starting with the various effects of high speed tracks.



(Refer Slide Time: 25:48)



The various effects are, the track, it may cause track irregularities which may result in pitching, rolling, bouncing and lateral oscillations of the vehicle and these types of oscillation of the vehicle or the movements they are known as parasitic movements. Pitching is like in the forward direction, rolling is on the lateral direction, bouncing is in upward direction and lateral oscillation is the transverse direction. Then, pressure and stresses due to resonance between the frequency of application of load and elastic oscillations of the track in whole or component is another problem of the high speed tracks.

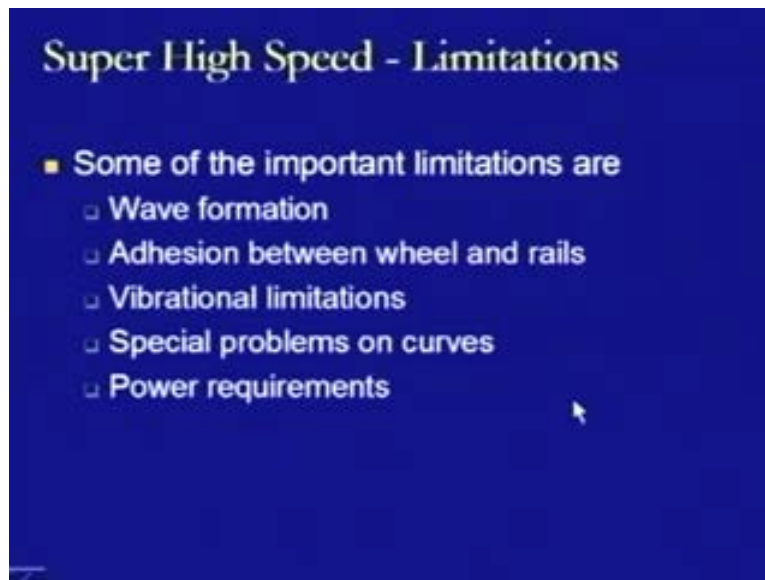
That is there is large amount of pressure and stresses because of resonance effect of the frequencies. The stresses due to inertia or springing action of track is another effect. Then, there are unbalanced weights which needs to be catered to, which may have the effect in terms of wearing of the surfaces of the defects which may be caused into the rail sections. Then, there is unsprung masses. Unsprung masses are the conditions, where we have the masses which cannot be moved on, so as to limitise their effect in terms of the negative aspects and suspension characteristics is another problem area of the high speed tracks. If the suspension characteristics are not good, then it will create more effects, more stresses on the rails as well as the overall track when the high speed trains will



move. Otherwise, the suspension characteristics are okay, then there will not be any such problem.

Now, once we have seen on the various effects of the high speed tracks, now the next thing which we can look at is the certain limitations which are associated with the so far high speed.

(Refer Slide Time: 28:02)

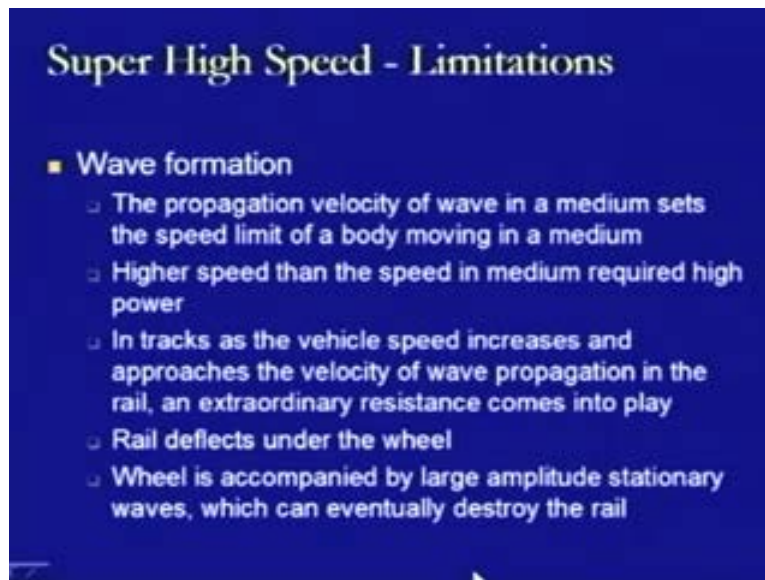


What we are interested in looking here is that we are looking at the reasons which may create an effect in restricting the overall speed of the track, from where those limitations are coming up and some of the important limitations are the formation of the wave on the rail sections, as we have seen in the case of the **creep** theory of the rail, there was wave formation theory and the wave is forming and moving in the longitudinal direction forward with the movement of the wheels, inducing the creep. That is the same type of wave formation condition here, but then how it limitises the speed will be seen.

Then, there is adhesion between the wheel and rails. That is another factor that there is certain amount of friction which always remains between the wheels and the rails and that is why and that is how the two things remain in adhesion with each other. There is no

separation and they are not going away from each other. So, that is another aspect which limits the speed. Then, there are vibrational limitations, how the vibrations are induced and how they limitise, we will be looking at this one. Then, special problems on the curve, specifically related to the provision of the cant and the centrifugal force. Then, the power requirement for the super high speed, this is another important area which limitises the overall speed of the movement.

(Refer Slide Time: 29:40)



**Super High Speed - Limitations**

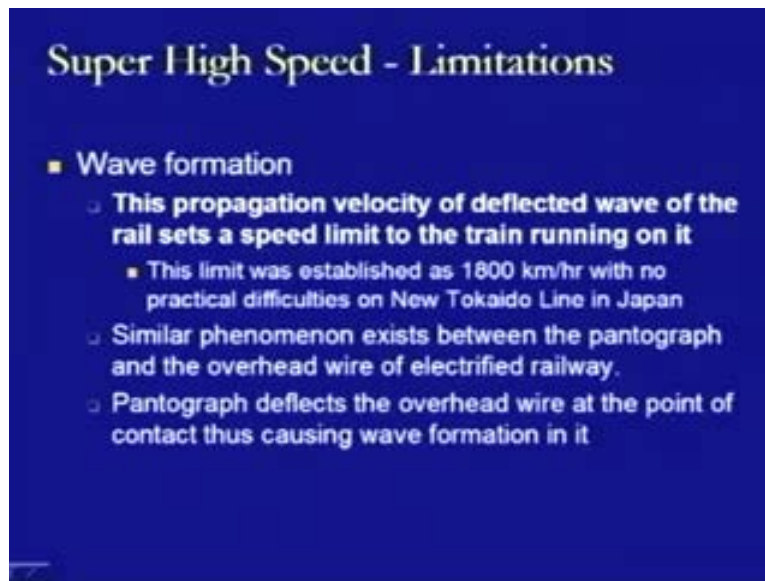
- Wave formation
  - The propagation velocity of wave in a medium sets the speed limit of a body moving in a medium
  - Higher speed than the speed in medium required high power
  - In tracks as the vehicle speed increases and approaches the velocity of wave propagation in the rail, an extraordinary resistance comes into play
  - Rail deflects under the wheel
  - Wheel is accompanied by large amplitude stationary waves, which can eventually destroy the rail

So, we will be looking at all these limitations one by one and we will start with the first one that is the wave formation. In the case of wave formation what happens is that there is a propagation velocity of wave in a medium and it sets the limit to the speed of a body moving in a medium. That is the concept of the wave formation condition. What happens is that as we have seen in the case of creep of rails, as soon as there is a load which is coming on the top of the rail through wheels, there will be a deflection at that point and due to the rigidity of the rail mass, this deflection in the downward direction will cause the uplifting of the rail section in forward as well as in the backward position of the wheel than the normal condition and that is what is the sort of a wave which has got propagated, which has got induced at that location.

Now, as the wheel moves forward, then this sort of a condition will also be moving forward. Now, that is what is a wave which is moving in the rail medium. Now, there can be a propagation velocity for this wave in the medium that is here the material of the rail and there is certain limitation on this propagation velocity on the basis of the characteristics of the material which are being used in that medium. Here it is rails and that is from where the speed limits are coming for that body which moves within a medium, because there are certain resistances which will be offered by the medium to the movement and those resistances need to be seen and with respect to those resistances we have to identify that what is going to be the maximum speed.

Higher speed than the speed in the medium require higher power. So, that is one thing. If we are interested in getting higher speed than the speed in medium, then it will be requiring a higher power condition, we have to provide more power to this type of a system. Now, as the vehicle speed increases in the tracks and approaches velocity of the wave propagation in the rail, then an extraordinary resistance comes into play means now both the wave propagation velocity and the track velocity, they are coming in combination with each other, equal to each other **than** the resistance is coming and in this case the rail deflects under the wheel. So, this is the case which is trying to limitise it and the wheel is accompanied by large amplitude stationary waves which can eventually destroy the rail.

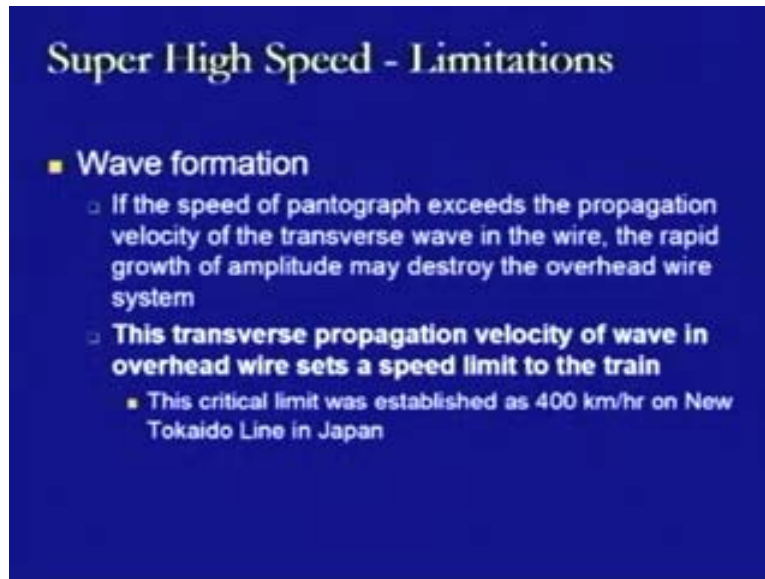
(Refer Slide Time: 32:47)



So, this propagation velocity of deflected wave of the rail sets a speed limit to the train running on it and this limit was established as 1800 kilometer per hour with no practical difficulties on New Tokaido line in Japan. That is the maximum speed which was practically experimentally found out which can be achieved and that is obviously going to be dependent on the material characteristics. The similar phenomenon exists between the pantograph and the overhead wire of electrified railway. In the case of electrified railway, locomotive is provided with the pantograph which is made up and down, so as to take the current from the top overhead wires. So, here when there is a continuous connectivity action between the pantograph and the overhead wire, then sort of a frequency in the wave propagation takes place also in these cases.

The pantograph deflects the overhead wire at the point of contact, thus causing wave formation in it.

(Refer Slide Time: 34:08)



## Super High Speed - Limitations

- Wave formation
  - If the speed of pantograph exceeds the propagation velocity of the transverse wave in the wire, the rapid growth of amplitude may destroy the overhead wire system
  - **This transverse propagation velocity of wave in overhead wire sets a speed limit to the train**
    - This critical limit was established as 400 km/hr on New Tokaido Line in Japan

So, once this wave is being formed, then what happens is that if the speed of the pantograph exceeds the propagation velocity of the transverse wave in the wire, a rapid growth of amplitude may destroy the overhead wire system. So, this is the basis for limiting the speed. So, if the pantograph speed increases and it becomes more than the speed of the transverse wave, then the amplitude may cause the failure of the overhead wire system and this transverse propagation velocity of wave in overhead wires sets a speed limit to the train and this critical limit is established as 400 kilometer per hour on again the same New Tokaido line in Japan.

(Refer Slide Time: 34:48)

## Super High Speed - Limitations

### ■ Wave formation

- *The speed can be increased by increasing the tension in overhead wire or by developing a lighter wire material*
- *Restricting factors are strength and conductivity of wire*

So, we see that the value comes out to be 400 kilometers per hour in the case of electrified tracks. The speed can be increased by increasing the tension in overhead wire or by developing a lighter wire material. These are the two ways by which we can improve upon the speed. But then, we cannot increase the tension in the overhead wire to a very high value, which otherwise also may cause the braking of the wires. That is one thing. Another thing is developing the lighter wire material is a part of a research and still the work is going on in this aspect. Then, restricting factors are in this case the strength and the conductivity of the wire, which may allow the propagation of the wave at certain velocity.

(Refer Slide Time: 35:37)

## Super High Speed - Limitations

### ■ Adhesion between Wheels and Rails

- The tractive force works as the reaction of rail due to adhesion between wheel and rail
- This adhesion force tends to decrease with the increase in speed
- But the train resistance increases approximately with the square of the speed
- If curves of adhesion force between wheel and rail, and train resistance are plotted with respect to velocity of train then the two curves will intersect each other.

Then, another aspect is the adhesion between the wheels and the rails and in this case, what happens is that the tractive force works as the reaction of rail due to adhesion between wheel and rail. This already we have, we know. We have understood this thing before and this adhesion force tends to decrease with the increase in speed, because that is related to the frictional force. But, the train resistance increases approximately with the square of the speed which we have already seen, which we have already discussed and computed when we discussed about the train resistances, where it was varying in terms of  $W V^2$ . If curves of adhesion force between wheel and rail and train resistance are plotted with respect to velocity of train, then the two curves will intersect each other.



(Refer Slide Time: 36:33)

## Super High Speed - Limitations

### ■ Adhesion between Wheels and Rails

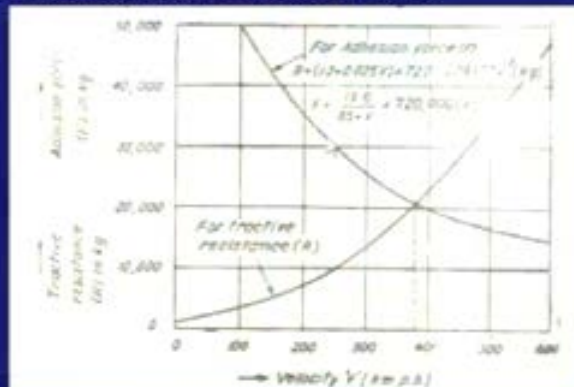
- If additional torque is applied above the speed related to point of intersection, the wheel slips on the rail and the torque cannot be utilized for accelerating the train

That is the thing which will happen and if additional torque is applied above the speed related to the point of intersection, the wheel slips on the rail and the torque cannot be utilized for accelerating the train. So, that is the limiting condition in the case of adhesion of wheels and rails. Now, whatever torque after this you are improving upon and you are providing will not be utilized to accelerate the train and therefore the speed or the velocity of the train cannot be increased further after this point.

(Refer Slide Time: 37:08)

## Super High Speed - Limitations

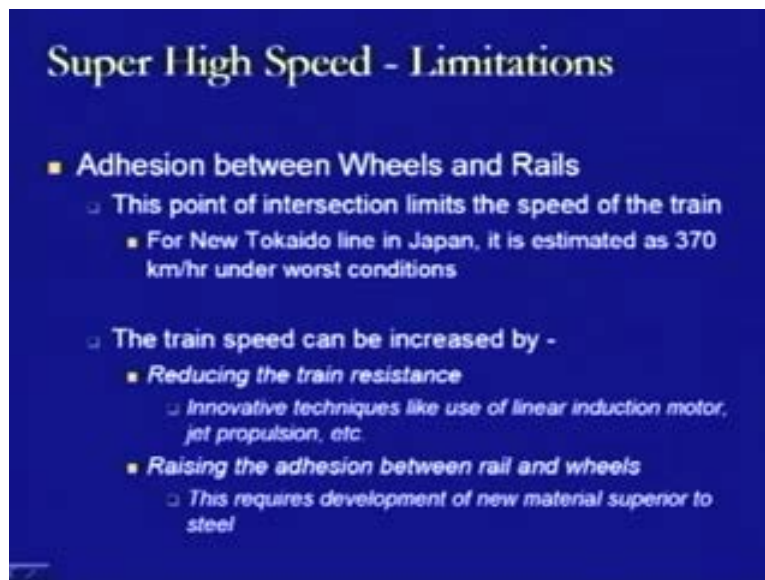
### ■ Adhesion between Wheels and Rails



This is the graph which is trying to show the same. Here, the velocity is being taken which is taken from zero kilometers per hour to 600 kilometers per hour and on the y-axis, we are having the two values. One is the adhesive force,  $F$  in kg and another one is tractive resistance,  $R$  in again kg and we have drawn for both the things the graph between those and the velocity and this is the curve for the adhesion force. That is the adhesion force keeps on reducing as the velocity keeps on increasing, whereas this is tractive resistance force which is increasing as the square of velocity as the velocity increases and therefore this curve goes like this.

Therefore, there is a point of intersection between these two curves that is the adhesion curve and the tractive resistance curve and this comes out to be here, which is very near to 400 kilometers per hour. At this particular value of 400 kilometers per hour, the tractive resistance comes out to be something like 20,000 kg's and if we can provide tractive effort more than this, then, even then that tractive force is not going to be helpful, because the adhesion will be reducing by a larger value and therefore, will not allow the movement in the normal condition and there will be a slip of the wheels over the rails.

(Refer Slide Time: 38:35)

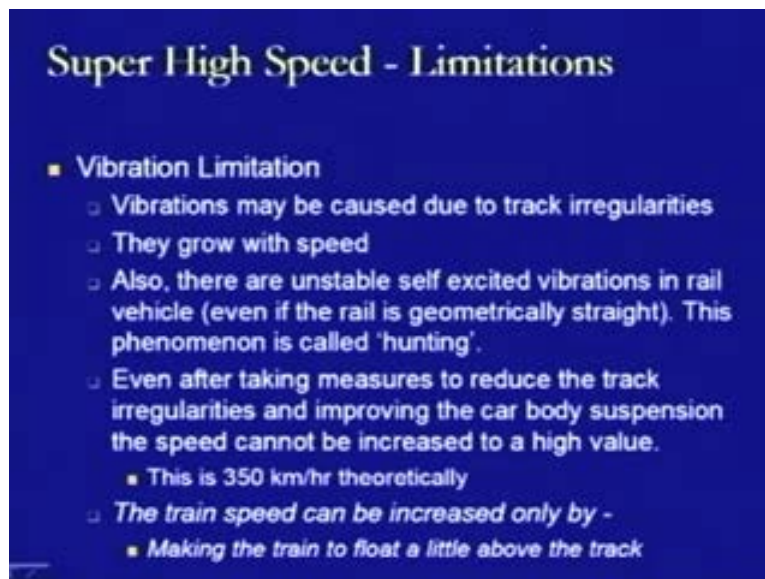


### Super High Speed - Limitations

- **Adhesion between Wheels and Rails**
  - This point of intersection limits the speed of the train
    - For New Tokaido line in Japan, it is estimated as 370 km/hr under worst conditions
  - The train speed can be increased by -
    - *Reducing the train resistance*
      - Innovative techniques like use of linear induction motor, jet propulsion, etc.
    - *Raising the adhesion between rail and wheels*
      - This requires development of new material superior to steel

So, this point of intersection limits the speed of the train and in the case of again, New Tokaido in Japan it was estimated as 370 kilometers per hour under the worst conditions. So, the train speed in this case where the adhesion between rails and wheels has been talked about can be increased by reducing the train resistance. That is there are innovative techniques like use of linear induction motor or jet propulsion, etc., that is what we can use and these are the new concepts of increasing the super high speeds and raising the adhesion between the rails and wheels is the another way and in this case we require a development of new material which is superior to the steel, so that better adhesion can be achieved.

(Refer Slide Time: 39:20)



**Super High Speed - Limitations**

- **Vibration Limitation**
  - Vibrations may be caused due to track irregularities
  - They grow with speed
  - Also, there are unstable self excited vibrations in rail vehicle (even if the rail is geometrically straight). This phenomenon is called 'hunting'.
  - Even after taking measures to reduce the track irregularities and improving the car body suspension the speed cannot be increased to a high value.
    - This is 350 km/hr theoretically
  - *The train speed can be increased only by -*
    - *Making the train to float a little above the track*

Then, there are vibrational limitations. In the case of this, the vibrations may be caused due to track irregularities and they grow with speed. Also, there are unstable self-excited vibrations in rail vehicle, even if the rail is geometrically straight. This phenomenon is called hunting and even after taking measures to reduce the track irregularities and improving the car body suspension system, the speed cannot be increased to a high value and theoretically this value has been found to be 350 kilometers per hour. So, by looking at the different aspects so far, this value is the minimum value which comes out to be 350 kilometers per hour.

In this case, where we can limitise the vibrations and effect of vibrations, the train speed can be increased only if we make the train to float a little above the track. That is where the effect of the track irregularities or the geometrics will be removed and the resistances will also become lesser from the track and therefore, the speeds can be increased to a much higher value and that is what is the concept of all the new techniques.

(Refer Slide Time: 40:45)



**Super High Speed - Limitations**

- **Special Problems on Curved Track**
  - Unequal wheel loads on inner and outer rails
    - Influence the safety of vehicle
  - Provision of super elevation on outer rail to counteract centrifugal force
    - Indiscriminant increase may cause uneasy feeling to passengers, vehicle overturning, etc.
    - Experiments on New Tokaido line in Japan established that maximum lateral acceleration of  $0.05\text{cm/sec}^2$  do not cause much discomfort and results in 180 mm of cant.

Then, there are some special problems on curve tracks like unequal wheel loads on inner and outer rails, which influences the safety of the vehicle. The provision of super elevation on outer rail to counteract the centrifugal force and what happens in this one is that there is an indiscriminant increase, which may cause uneasy feeling to the passengers or may cause the vehicle overturning, etc., because there is very high super elevation to be provided and experiments on New Tokaido line in Japan established that maximum lateral acceleration of 0.05 centimeter per second square do not cause much discomfort and results in 180 mm of the cant. So, that is the maximum amount of value of cant, which can be provided, this 180 mm.

(Refer Slide Time: 41:31)

## Super High Speed - Limitations

- **Special Problems on Curved Track**
  - The curve radius of 2000 m and elevation of 180 mm will provide a balancing speed of 200 km/hr
  - *The train speed can be increased by -*
    - *Increasing the radius of curve*

Further, the curve radius of 2000 meters and elevation of 180 mm will provide a balancing speed of 220 kilometer per hour. So, means the value on the curve track reduces to this value so wherever the curves are provided then the speed is to be restricted and in these cases the train speed can be increased by increasing the radius of the curve

(Refer Slide Time: 41:56)

## Super High Speed – Power

- **Power Requirements**
  - Specific power, defined as the power required to move 1 ton of passenger rolling stock, is correlated with air resistance, gradient, speed and acceleration
  - It is observed that with the increase in speed, the requirement of power to overcome the resistance and to accelerate the train goes up very steeply.

Now, we come to another aspect of super high speed that is the power and the power requirements. There is a specific power, defined as the power required to move 1 ton of passenger rolling stock which is correlated with air resistance, gradient resistance, speed, and acceleration resistances, etc., and it is being observed that with the increase in speed, the requirement of power to overcome the resistance and to accelerate the train goes up very steeply. That is already we have seen when we talked about the rolling power requirement of a locomotive, which is directly related with the resistances offered by the track and the tests indicated that at the speed of 300 kilometers per hour, the air resistance takes about 95% of the tractions power and only 5% of the power is devoted to suspension and guidance.

(Refer Slide Time: 42:57)



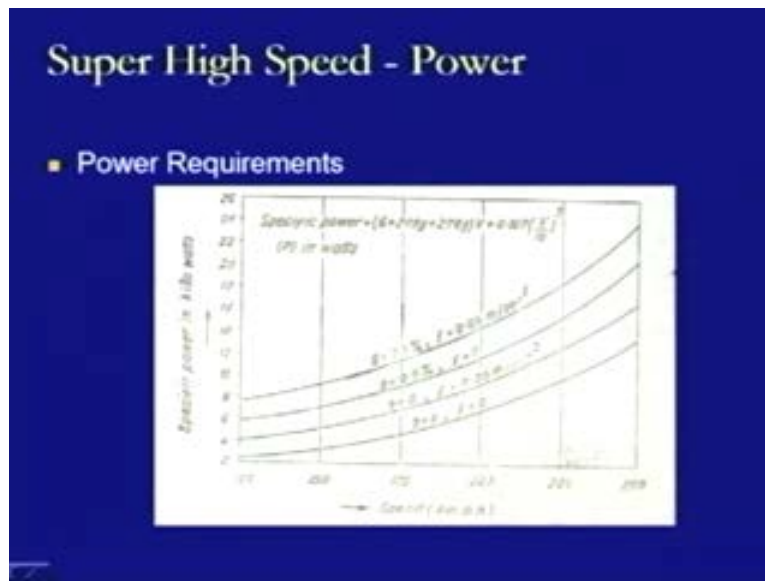
**Super High Speed – Power**

- **Power Requirements**
  - Tests indicated that at a speed of 300 km/hr, air resistance takes about 95% of the tractions power and only 5% of the power is devoted to suspension and guidance.
  - *Therefore, steel wheels on rails offers greatest economy for a given speed.*

So, that is the amount of power which is being taken by the resistances and rest of the power which is available is very less for the guidance system. Therefore, steel wheels on rails offers greatest economy for a given speed.



(Refer Slide Time: 43:13)



This is a diagram which tries to define the relation between the specific power in kilowatts and the speed for different values of  $g$  that is the grades and the different values of  $F$  in meter per second square, which is the acceleration and we have the specific power equation by which we can find out the power. So, that correlation is what we see that, as the speed increases, for the same value of  $g$ , the specific power increases if the value of  $F$  changes or if for the same value of  $F$ , if the  $g$  value changes, then also the specific power increases. But, that increase is at a higher rate as compared to the change in the value of  $F$ .

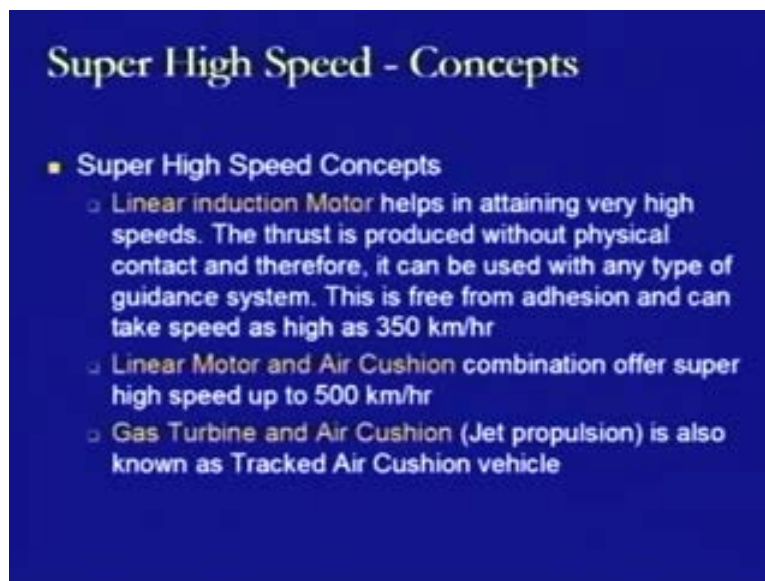


(Refer Slide Time: 44:02)



Now, we come to the super high speed concepts. How we can attain the super high speeds, there are different ways. One is the linear motor and wheel case. Another one is linear motor and air cushion vehicles. Then gas turbine and air cushion vehicles which are the jet propulsion vehicles and magnetic levitation vehicles.

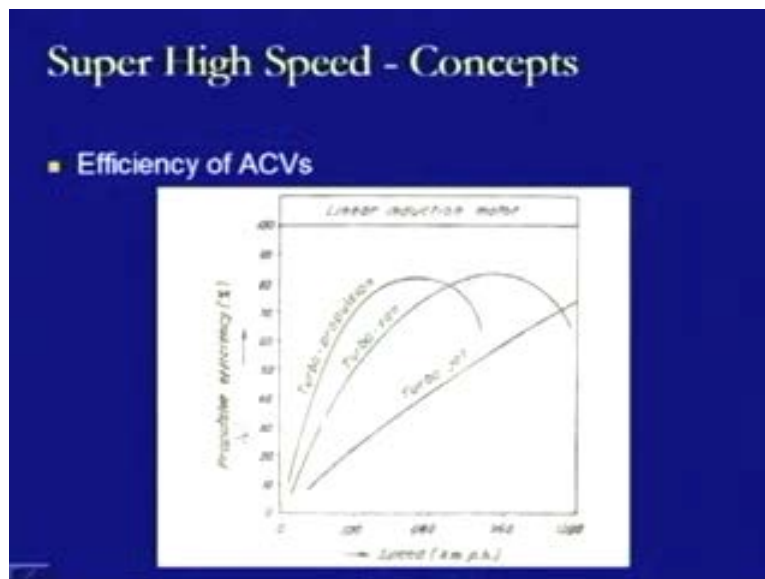
(Refer Slide Time: 44:27)



We will be looking at some of these concepts. The linear induction motor is one which helps in attaining very high speeds. The thrust is produced without physical contact and therefore, it can be used with any type of guidance system and this is free from adhesion and can take speed as high as 350 kilometers per hour. So, it is providing the thrust from the backward direction by using the air. Then, linear induction and air cushion method, this is a combination which offers super high speed of up to 500 kilometers per hour, where the vehicle is supposed to move over the air cushion, thereby reducing the resistances which are being offered by the track and due to this reduction in resistances offered by the track, the speed increases from 350 to 500 kilometer per hour.

Then, in the case of gas turbine and air cushion or jet propulsion system which is also known as tracked air cushion vehicle system, a gas turbine is provided instead of linear induction motor and with the help of this gas turbine, we try to achieve the higher speeds.

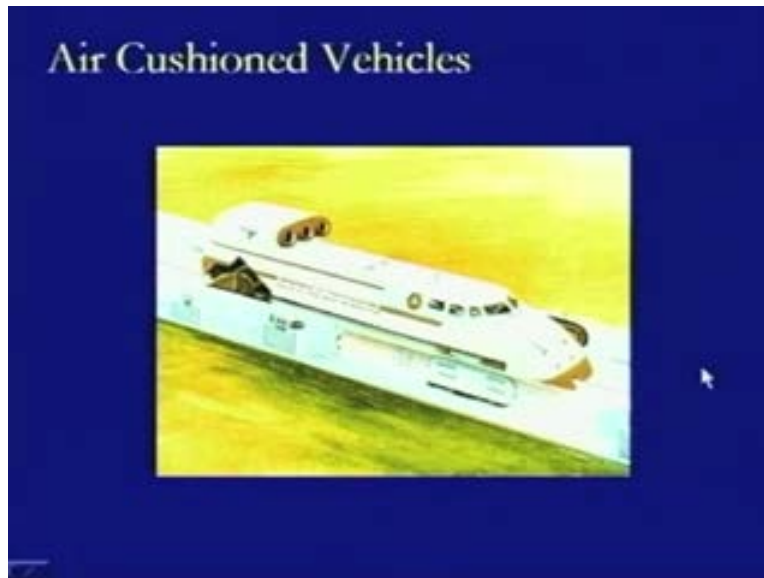
(Refer Slide Time: 45:45)



This is one of the graph which tries to define the efficiency of all these air cushioned vehicles, ACV's and here in this one, the correlation has been shown with respect to the speed on the x-axis and **propulsive** efficiency in percent on the y-axis. In the case of a linear induction motor, it is at 100% and goes constantly. That means whatever is the speed that value or propulsive efficiency remains constant, whereas in the case of turbo

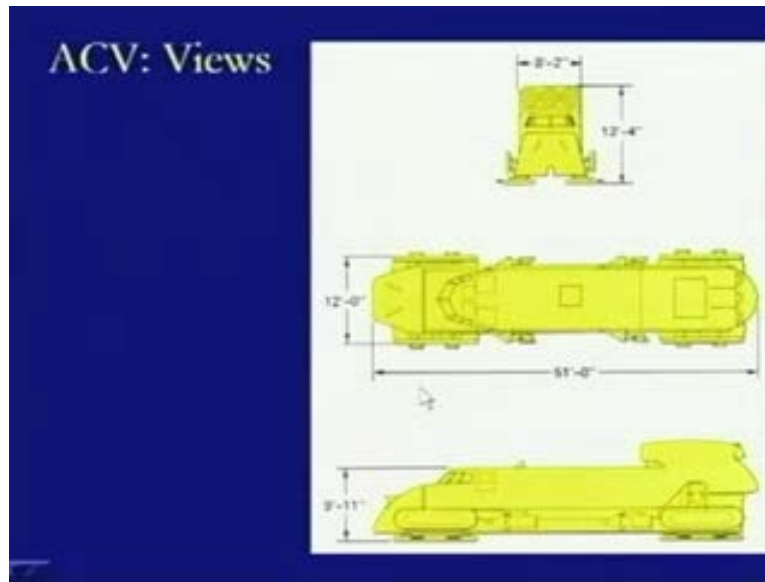
jet or turbo fan or turbo propulsions, the values are changing and we found at same, almost same amount of value is being achieved in the case of turbo fan or turbo propulsion, but at a higher speed. So, that is the comparison between the three types of the propulsive systems which can be provided on air cushioned vehicles.

(Refer Slide Time: 46:47)



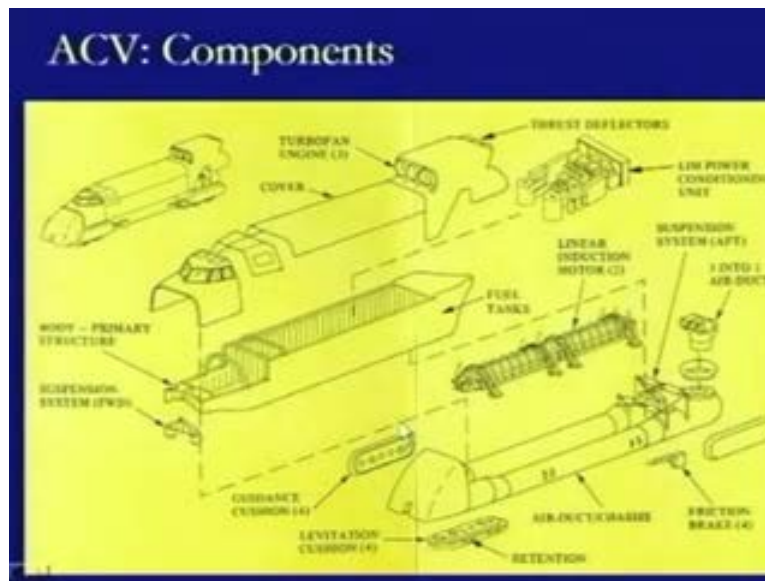
This is one of photograph of an air cushioned vehicle and here this vehicle is moving in this direction provided with aerodynamic profile and this is the place where the thrust or the propulsive condition is being created by which the thrust goes in the backward direction and the vehicle moves in the forward direction and it is provided by the guidance being provided on the two sides. We can see this brown colored oval shape condition here and white based oval shape condition. These are the cushions which have been provided, which works as a guidance system for this vehicle to move within this track, so that if there is any lateral movement it comes back to the normal average condition of the track.

(Refer Slide Time: 47:35)



These are the three views of the same air cushioned vehicle. This is the back view where these are the three motors being provided. They are the three linear induction motors being provided. This is the plan of the system, where this is the aerodynamic profile. Here the sitting condition and the person sits here and then this is the place where we have installed the engine which takes the power from this induction motors and it is taken downwards and it comes to the system being provided at the bottom here and this is what is the side cushion being shown and this is the bottom support being provided.

(Refer Slide Time: 48:26)

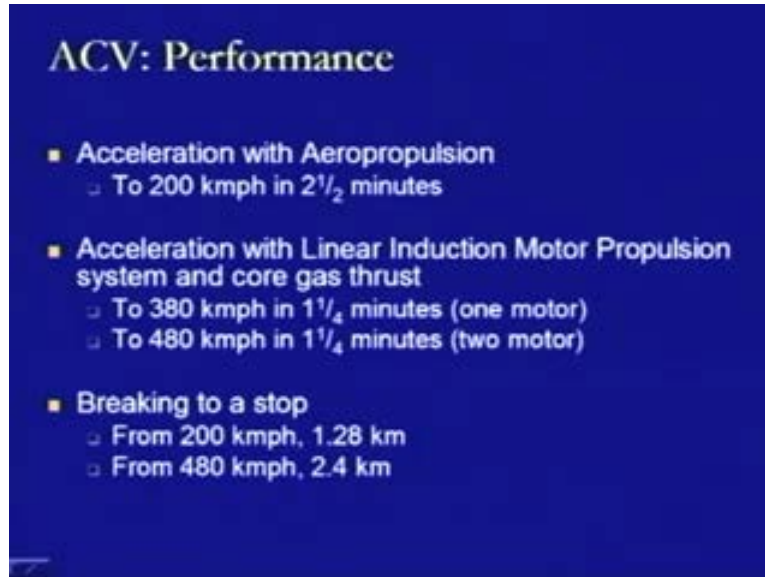


This is another diagram which tries to show the various components of the air cushioned vehicle and this is the air cushioned vehicle. In this case, this is the top one body which is known as the cover, where the turbo engines of three numbers are being here and at the back, there are thrust deflectors. This is fitted with this linear induction motor power conditioning unit. So, this goes inside in this one and this is the location. This is how it comes. Then, the fuel tank is provided at this location. This is the primary body structure of this vehicle. Then, it is provided with suspension system. This suspension system is for the forward position; similarly is the suspension system which is provided at the other side.

The side cushion system is shown. This is the side cushion system being shown here, this one. This linear induction motor number 2 which is placed at this level, fitted in here and there is a real suspension system at this location. Then, there are air duct that goes and this connectivity is going to air ducts at this location. These are the air ducts by which the thrust will be coming out at the backward direction. So, this is being connected to this linear induction motor through LIM power conditioning unit and it goes here and then, the air duct ... this is being provided. Then, the friction brakes are also provided and at

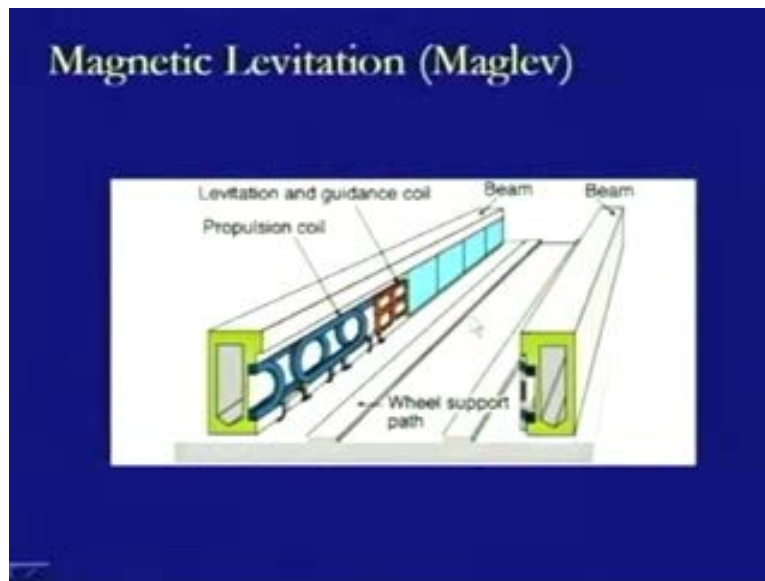
the bottom, there is a retention, which is also levitation cushion, which helps to provide a support without creating any damage to the main primary body of the ACV.

(Refer Slide Time: 50:12)



The performance of this ACV is with respect to acceleration and aero propulsion. It can take a speed of 200 kilometers per hour in two and half minutes and the acceleration with linear induction motor propulsion system and core gas thrust is in this case, it is 380 kilometers per hour in one and one by four minutes with one motor or 480 kilometers per hour in one and one by four minutes with two motors and breaking to a stop from 200 kilometers per hour speed within 1.28 kilometer it can be stopped and at a speed of 480 kilometers per hour and within a distance of 2.4 kilometers, this can be brought to a stop condition.

(Refer Slide Time: 51:02)

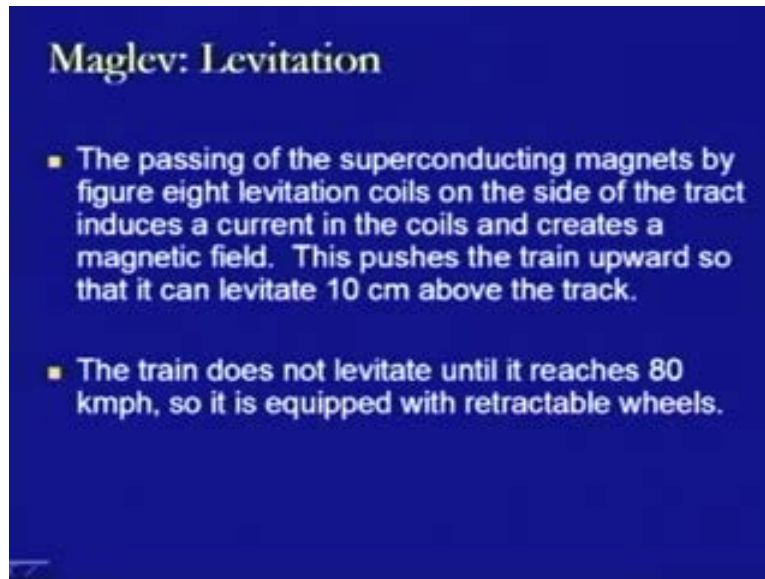


Then, another system which is used for the super high speed is the magnetic levitation in short known as Maglev. This is one of the costliest system, which uses the magnetic forces for propulsion as well as support and guidance and control and it is in general used as a design feature only. But now, China is implementing this one for looking at, to provide the connectivity from airports to the Olympic game village and travel will be through this magnetic levitation system.

How it works, we will be looking at the system. This is the support structure of magnetic levitation system. These are the wheel support paths being shown here and these are the coils being provided on the two sides. So, this is one beam, this is another beam which encompasses the coils. This is known as the propulsion coils as well as there is a levitation and a guidance coil. The propulsion coil is in the form of this big oval shape being overlapped over each other, whereas the levitation and guidance coil is in the form of a shape of a ..... structure. So, we will be using this propulsion and the levitation, guidance coil for the movement of the vehicle over these support paths and as soon as it takes a higher speed, then it will come into the, it will get lifted from this base and it will be moving into the air. So, there will be some gap between this and the base of the vehicle.



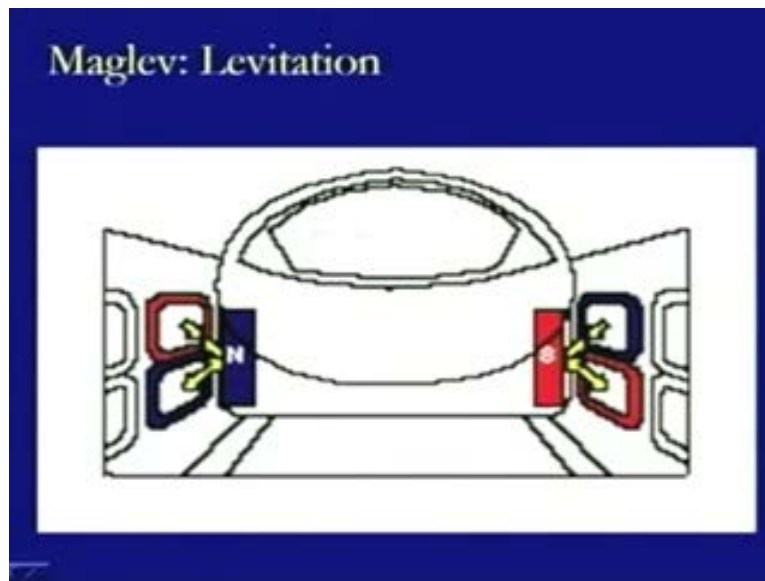
(Refer Slide Time: 52:40)



So, the passing of the superconducting magnets by figure eight levitation coils on the side of the track, induces a current in the coils and creates a magnetic field. This pushes the train upward, so that it can levitate 10 centimeter above the track. So, in the very starting what we do is that we pass the current and due to these super conducting magnets, the current will come into the coils and the magnetic field will get set on and this will help in rising the overall structure of the train 10 centimeter above the track.

So, this is the very first condition which will be created. Now, the train does not levitate until it reaches 80 kilometer per hour. So, it is equipped with retractable wheels. So, this is another condition in this one that it is not going to get levitate unless and until it reaches a speed of 80 kilometers per hour. So, it has to be provided with some wheel, so that it can move on the wheel still it reaches a value of 80 kilometers per hour.

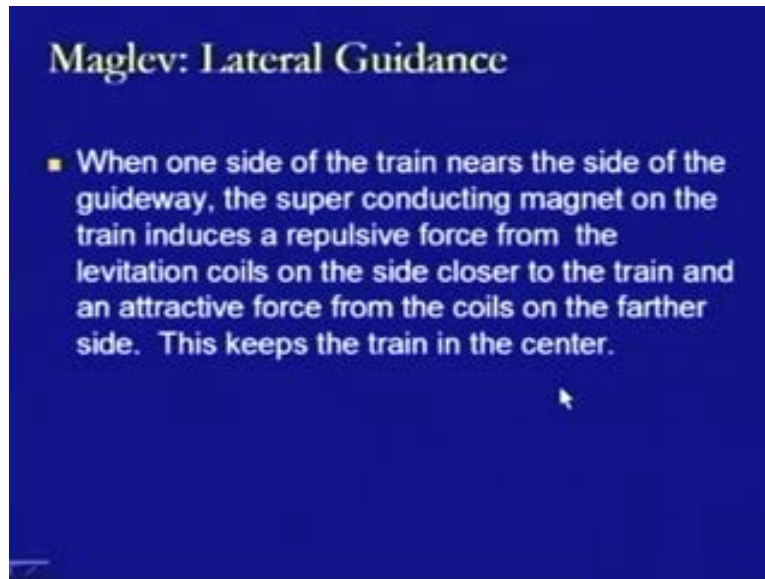
(Refer Slide Time: 53:52)



And this is a system which is working here and this is the vehicle which is moving on these two guidance paths or wheel paths. It is provided with superconductive coil on this side as well the superconductive coil on this side. This is working as a north pole and this is working as a south pole and this is the eight structure, which is levitation and superconducting coil and in this one with respect to this north superconducting coil, on board of the vehicle, this becomes north pole and this red becomes the south pole.

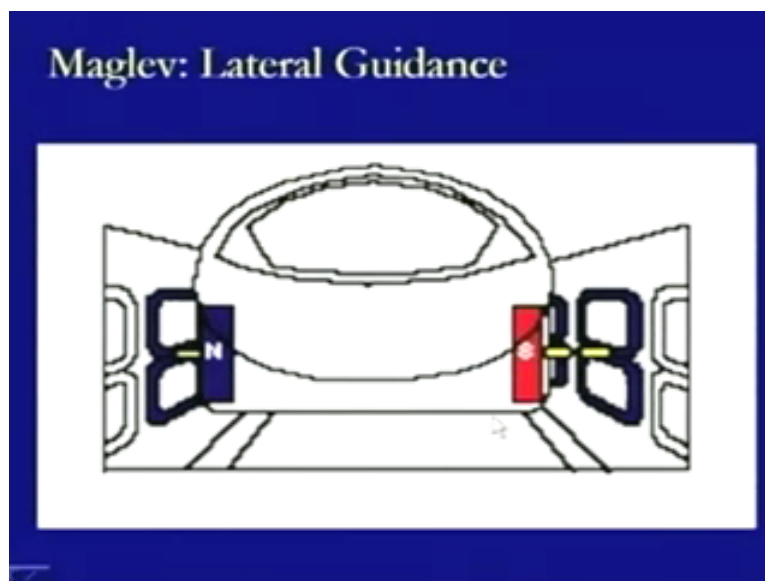
Similarly for this south pole, this becomes north pole and this becomes the south pole. So, there is an attraction between these two. But, there is repulsion between these two. Similarly, there is repulsion, there is attraction between these two, but there is repulsion between these two and this helps in maintaining the overall vehicle in the center of these two guidance systems on the wheel path. That is how it is being maintained in position.

(Refer Slide Time: 54:57)



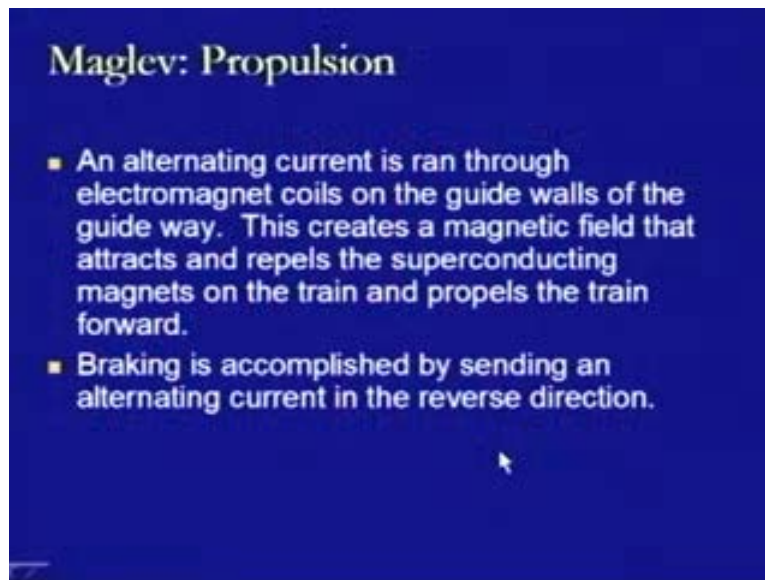
So, that is what is the lateral guidance. When the side of the train nears the side of the guide way, when it comes to one side of the guide way, so the super conducting magnet on the train induces a repulsive force from the levitation coils on the side closer to the train and an attractive force from the coils on the farther side and this keeps the train in the center.

(Refer Slide Time: 55:21)



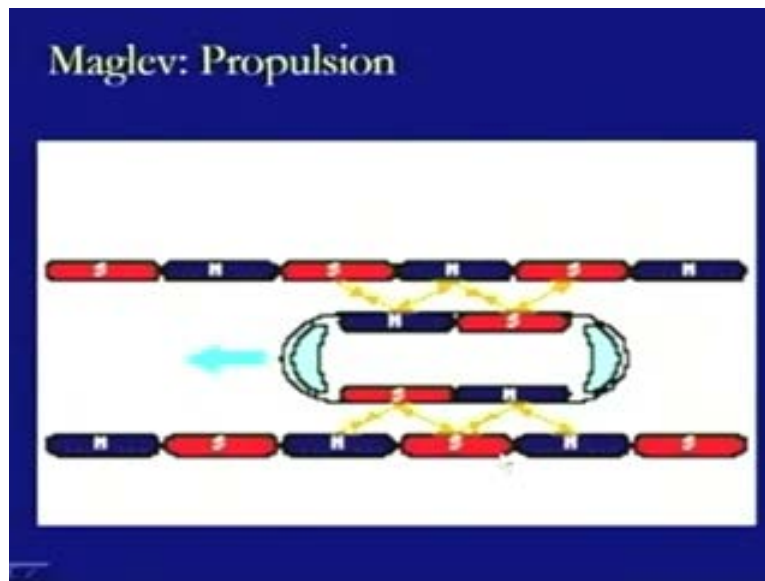
So, this is happening that this train has shifted, as we can see towards this side, this is coming on this one. So, this whole of the coil will become north pole and this is north pole. So, there will be a repulsion here where this also will become north pole and this is the south pole and there will be attraction in this one. So, it will try to shift this side and as soon as it becomes the same condition as we have seen in the previous diagram it will be centered.

(Refer Slide Time: 55:50)



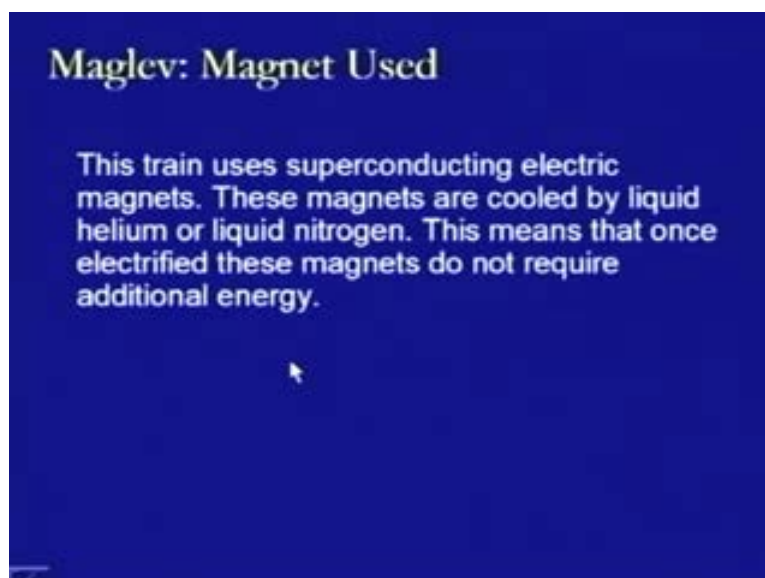
Similarly, we are talking about propulsion in this case. An alternating current is ran through electromagnet coils on the guide walls of the guide way and this creates a magnetic field that attracts and repels the superconducting magnets on the train and propels the train forward and the braking is accomplished by sending an alternating current in the reverse direction. That is how it is accelerated or deaccelerated.

(Refer Slide Time: 56:17)



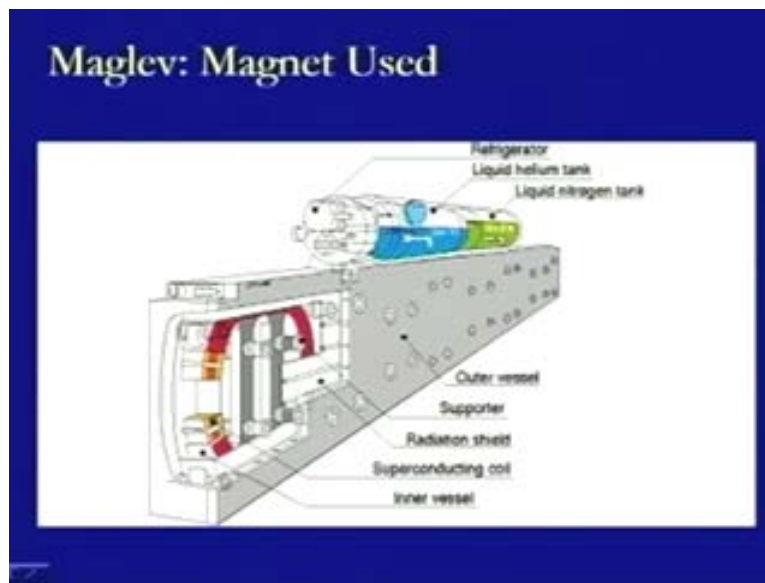
This is what is being shown here. This is the vehicle moving in this direction. So, this is two superconducting magnet on this side. So, this shows north pole, this is south. Opposite to this one, this is south and this is north and then these are the propulsive superconducting magnets. So, with respect to this north this is south, so it is attracting. Similarly, for this south there is north, this is attracting and this how with the attraction, with the help of this attraction it moves in this forward direction.

(Refer Slide Time: 56:52)



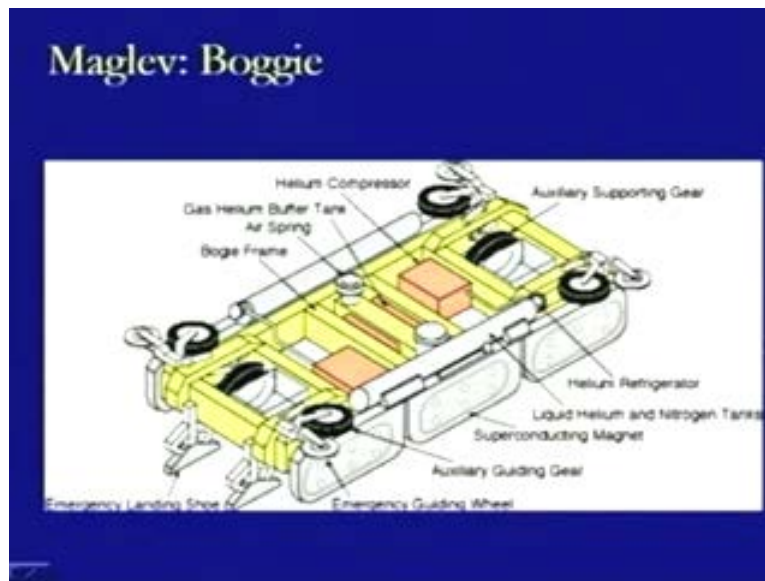
The amount of this attraction is so high that it can take higher, very, very high speed. This train uses superconducting electric magnets and these magnets are cooled by liquid helium or liquid nitrogen. This means that once electrified, these magnets do not require additional energy. This is another important thing. As soon as they get electrified, no additional energy is required to operate the system.

(Refer Slide Time: 57:17)



Here what we are trying, this is a refrigerator and this is a liquid helium tank and liquid nitrogen tank which is used to cool the superconductive magnet being shown here, with this is outer vessel, this is radiating shields, superconducting coil is being provided here. This is one super conducting coil and then this is inner vessel.

(Refer Slide Time: 57:38)



And this is bogie of the maglev, where these are the super conducting magnets being placed and this is the helium and nitrogen tanks used, so as to make them cool and then these are the wheels system which has come inside, but as soon as it has attained the speed of 80 kilometers. If it is less than 80 kilometers, they will go out and will move below the base system of this one and these are the emergency landing shoes being shown. If the wheels are not working, then this vehicle can land on these emergency shoes.



(Refer Slide Time: 58:18)



These are some of the figures and photographs of these super high speed vehicles. This is one and this is another shape, aerodynamic shape of the same vehicle.

(Refer Slide Time: 58:28)



So, what we have discussed in today's lecture is how we can attain the high speeds or the super high speeds and what are the concepts and what are the limitations in achieving those super high speeds. If we can and it means it requires to do some more research in

the area of materials and to improve upon to reduce the limitations by which the speed of the track is being limited. I understand that you have enjoyed what we have discussed so far in the case of railway engineering, about the different aspects of railway engineering and now we will be shifting from railway engineering to the airport engineering and we will be looking at various respects of airport engineering in the coming lectures. Till then, good bye and thank you.