

Safe and Eco Friendly Train Traction System with No Rails

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ABSTRACT

In this research paper, a novel train traction system is described. In this system, the vehicle is lifted like a hovercraft by air cushion and the traction is achieved by using horizontally mounted all-wheel drive. Chance of derailment is completely eliminated and wherein even in the event of failure of few traction wheel stations during run, the train remains mobile with absolute safety even at high speeds. All-wheel drive traction is powered by overhead electrification to maintain high power to weight ratio and faster acceleration. In the present invention, no rail is used. This eliminates the enormous cost of laying the complex and expensive railway tracks. Other advantages include the lack of exhaust fumes and carbon emissions at point of use especially in countries where electricity comes primarily from non-fossil sources, less noise, lower maintenance requirements of the traction units. In case, where the availability or laying the overhead electrification is an issue, the present invention has the potential to adopt alternate power sources such as petrol or diesel or gas turbine or jet engines or hybrid power sources for traction. But ecological issues may have to be compromised in such cases. The present invention has a potentially wide scope to revolutionize urban and suburban railway traction (both passengers and goods) and long distance traction. For proving the technical feasibility, a working model was developed. In this paper, the results from the working model are discussed in detail. (Indian patent and PCT application are pending).

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INTRODUCTION

Conventional trains use complex and expensive rail beds needed to support the entire weight on two thin rails. At high speeds, trains suffer from a form of instability known as "hunting oscillation" that forces the flanges on the sides of the wheels to hit the sides of the rails, as if they were rounding a tight bend. If the frequency of these hits increased to the point, where they became a major form of drag, rolling resistance is dramatically increased and potentially causing a derailment [1]. That meant that for travel above some critical speed, a hovercraft could be more efficient than a wheeled vehicle of the same weight. In practice it has been found that air-cushion vehicles can be overloaded by as much as 100 percent of the design payload and still operate. [2]

With the Hovercrafts, it was thought that pads of high-pressure air could replace the wheels of a car. However, three main difficulties became apparent: 1. Pads of high-pressure air proved difficult and wasteful of power to lift the car high enough for it to travel over any but the smoothest surface. 2. The difficulty of propulsion. As soon as physical contact with the ground is lost, a new method of propulsion had to be devised to replace that usually supplied by the wheels. 3. Problem of steering the Hovercraft. Because of these problems, the Hover

car concept has never been a reality and commercial use has moved towards the Hover train but even then with limited success. The present invention addresses all these problems.

Among all forms of energies those exist, Green Energy is the need of the day in this world struggling with global warming and its potential hazards to the very existence of living beings on planet Earth. Yawning gap between desirable and current scenario in foreseeable future is a matter of serious concern. The sustenance of life is critically dependent on energy transformations and since only a tiny fraction of the original chemical energy in fossils is used for work, efficient transformation is, therefore a necessity at least till such time renewable energy sources take over a significant portion of total energy requirement. The present invention addresses this critical ecological issue.

One of the earliest hover-train concepts predates hovercraft by decades; in the early 1930s Andrew Kucher, an engineer at Ford, came up with the idea of using compressed air to provide lift as a form of lubrication. This led to the Levapad concept, where compressed air was blown out of small metal disks, shaped much like a poppet valve. The Levapad required extremely flat surfaces to work on, either metal plates, or as originally intended, the very smooth concrete of a factory floor. [3]



It appears that no effort was put into vehicle use until the 1950s, when several efforts used Levapad-like arrangements running on conventional rails as a way to avoid the hunting problems and provide high-speed service. An article in *Modern Mechanics*, October 1958 publication [4] is one of the first popular introductions of the Levapad concept. The article focuses on cars, based on Ford's prototype "Glideair" vehicle, but quotes Kucher noting "We look upon Glideair as a new form of high-speed land transportation, probably in the field of rail surface travel, for fast trips of distances of up to about 1,000 miles".

Once air-cushion suspension was proved practical in Hovercraft, the system was quickly applied to other forms of transport, and it soon became clear that a tracked vehicle, similar to a train or monorail, would benefit considerably from the lack of friction inherent in an air-cushion system. A French company was the first in the world to produce a practical device, and a later version of its machine was considered for a high-speed link between Orleans and Paris by the mid-1970s. The system used air-cushion pads above and at the side of a single concrete track to support the "aero-train," while propulsion was via a large ducted fan mounted at the rear [5].

Research is also proceeding in other countries. Air-cushion trains have speed potentials of up to 300 miles (480 kilometers) per hour; track costs are relatively low because of the simple concrete structure involved, which can be elevated on pylons, laid on the surface, or sunk in tunnels. Engineers in Britain, the United States, France, and Germany see this kind of high-speed surface transport as a means of connecting large urban centers with each other and with international airports [6].

What was lacking from all of them was a suitable way to move the vehicles forward - since the whole idea of the hover-train concept was to eliminate any physical contact with the running surface, especially wheels, some sort of contact-less thrust would have to be provided. There were various proposals using air ducted from the lift fans, propeller, or even jet engines,[4] but none of these could approach the efficiency of an electric motor powering a wheel. Many maglev projects are controversial, and the technological potential, adoption prospects and economics of maglev systems have often been hotly debated. The Shanghai system has been accused of being a white elephant by critics and opponents [7].

In this paper, the complete description of the novel, safe and eco-friendly train traction system is discussed. While selecting the major component parts, the adaptability of the present invention with respect to the contemporary technology is studied with the support of prior disclosures and literature publications. This paper will go into detail, discussing the comparisons of various options in selecting the major components. In order to prove the technical feasibility of the present invention, a simple working model was developed

using components available from the local commercial market. Discussions on the construction of working model, matching of its actual performance with the theoretical performance and comparison with wheeled vehicles of equal mass and speed are included in this paper.

GENERAL DESCRIPTION OF THE PRESENT INVENTION

Figure 1 describes the self-propelled multi-carriage unit formation of the safe and eco-friendly train traction system of the present invention. As shown in Figure 1, each of the units in the train formation is floating and moves on the air cushion generated by motor powered fans mounted individually at each unit. Since the entire train formation is floating and moving on the air cushion, the vehicle pressure on the ground and the ground friction are reduced drastically which enables a simple motor powered horizontally mounted all-wheel drive sufficient enough to pull the entire formation at very high speeds. Overhead electrification is used in the present invention to maintain high power to weight ratio and faster acceleration.

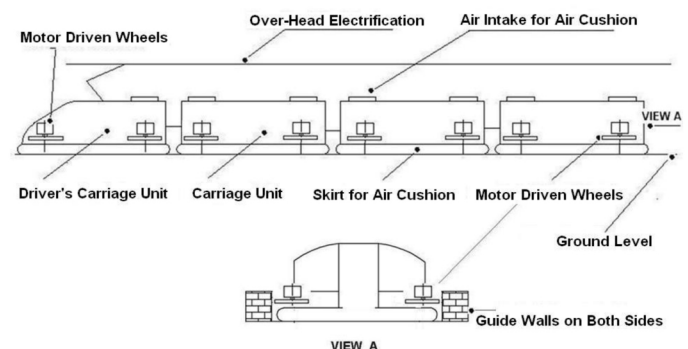


Figure 1. Multi-carriage unit formation of the safe and eco-friendly train traction system of the present invention.

As illustrated in Figure 1, the novel horizontally mounted driving wheels run inside a simple guiding channel with two flat vertical guide walls. With this novel arrangement, chance of derailment is completely eliminated and wherein even in the event of failure of few traction wheel stations during run, the train remains mobile with absolute safety even at high speeds. In case, where the availability or laying the overhead electrification is an issue, especially where tunnels and bridges and other obstructions have to be altered for clearance, the present invention has the potential to adopt alternate power sources such as petrol or diesel or gas turbine or jet engines or hybrid power sources for traction. But ecological issues may have to be compromised in such cases.

The selection of suitable major components in making the novel train traction system is discussed in the following paragraphs. The advantages and disadvantages of each selection are presented with citations based on prior disclosures and literature publications.

LIFT BY AIR-CUSHION SIMILAR TO HOVERCRAFT MODEL

Figure 2 and Figure 3 illustrate the construction of the multi-carriage units of the train formation. As shown in Figure 2, a centrifugal fan driven by an electric motor directly or through a gear box creates air cushion underside of the vehicle which lifts the vehicle off the ground to eliminate ground friction. A centrifugal fan is preferred here because the volume of air needed is very large. Whereas a conventional propeller is designed to be most efficient in open air like on an aircraft [8]. Also the fan needs to force air into the chamber below the vehicle to maintain a specific pressure. Propellers again are not efficient in applications when an air backpressure will be applied to the propeller blades as they rotate.

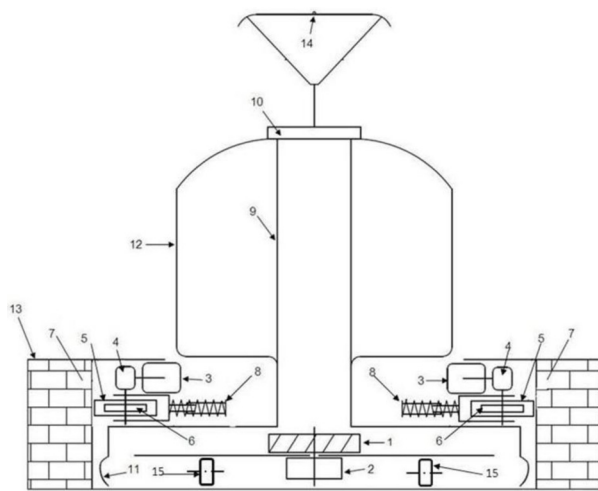


Figure 2. Arrangement of Major Systems in the Safe and Eco-Friendly Train Traction System of the present invention. 1. Centrifugal Fan, 2. Motor, 3. Traction Motor, 4. Gear Box (optional), 5. Traction Wheel, 6. Brake, 7. Guide Walls, 8. Linear Actuator cum Damper, 9. Air Duct, 10. Air Intake, 11. Skirt for Air Cushion, 12. Coach, 13. Platform, 14. Over-Head Electrification, 15. Landing Wheels with Brakes

Centrifugal fan powered by overhead electrification sucks air through the air duct, as shown in Figure 2 into the center of the fan and the slats force it out at the edges with high pressure. Due to lift and suspension of vehicle using air cushion, small imperfections in the ground surface would have no effect on the ride quality, so the complexity of the suspension system could be reduced. Additionally, since the load is spread out over the surface of the lifting pads, here the entire underside of the vehicle, the pressure on the running surface is greatly reduced - about 1/10000th the pressure of a train wheel, about 1/20th of the pressure of a tire on a road.[9]

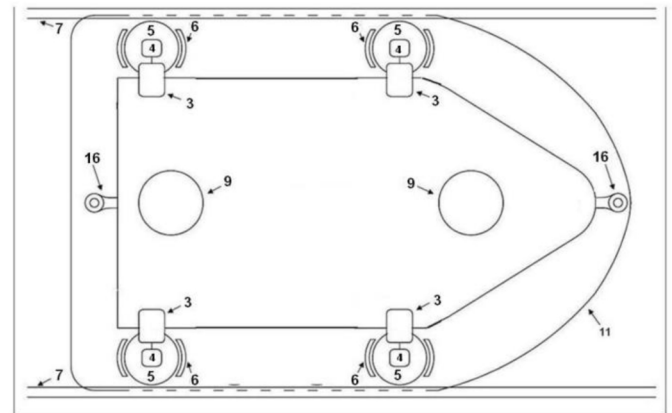


Figure 3. Top View of the Driver's Carriage Unit of the present invention. 3. Traction Motor, 4. Gear Box (optional), 5. Traction Wheel, 6. Brake, 7. Guide Walls, 9. Air Duct, 11. Skirt for Air Cushion, 16. Coupling for Multiple Carriage Units

These two properties meant that the running surface could be considerably simpler than the surface needed to support the same vehicle on wheels. This vehicle could be supported on surfaces similar to existing light-duty roadways, instead of the much more complex and expensive rail beds needed for conventional trains. This could dramatically reduce infrastructure capital costs of building new lines and offer a path to widespread use of safe high-speed trains.

As shown in Figure 2 and Figure 3, the skirts in the shape of a semicircle, is fastened around the perimeter of the vehicle. The inflated skirt forms a semicircular cross section. Materials used in the skirts have varied from the original rubberized fabric, through pure rubber and nylon, to a lamination of nylon and a proprietary plastic known as neoprene.[2] Bonding between the different layers have to be especially strong; otherwise the fabric delaminates under the severe conditions of wear and loses its tear resistance.

MOBILITY OF THE VEHICLE

In the present invention, since the weight of the entire train formation is already supported by air cushion, the horizontally mounted all wheel traction motor drive will need to provide only a fraction of the thrust required for mobility of the vehicle compared with other forms of transportation. Hence the construction of the traction system in the present invention is much lighter and simpler when compared with the other forms of train locomotive systems. As shown in Figure 2, a simple, horizontally mounted all-wheel traction motor drive powered by overhead electrification is used to propel the entire train formation at very high speeds. This also helps to maintain high power to weight ratio and faster acceleration. The horizontally mounted traction wheels roll over no rail way tracks but over a flat surface on the vertical side walls of the simple guiding channel. This eliminates the enormous cost of laying the complex and expensive railway tracks and completely eliminates the chance of derailment and provides excellent stability even during high speed run.

The all-wheel drive with an individual traction motor on each wheel station has certain advantages. Motive force can be divided to several wheels, power required for traction can be divided between motors, and more, smaller motors are easier to place inside the body. The weight of traction system is spread evenly throughout which helps in better vehicle stability. Voltage on motors of one particular side can be changed with serial or parallel connection of the motors which helps during steering. Even if few traction wheel stations fail during run, the train remains mobile providing absolute safety even at high speeds.

As illustrated in [Figure 2](#), each wheel station is consisting of a traction motor powered by overhead electrification, a simple optional gear box, a horizontally mounted wheel, a linear actuator cum damper and a brake system. In addition to the friction braking, regenerative braking is also used in the present method for better energy management during braking and reduced frictional wear of the friction brakes. Each of the above mobility elements of the present invention is described as follows.

OPTIONS OF TRACTION MOTORS

The present invention demonstrates a capability to use a wide classification of traction motors. This includes the traditional series wound DC motors, AC induction asynchronous traction motors, synchronous AC motors, wheel hub motors and Permanent Magnet Brushless Motors. Each classification of these motors is discussed in the following paragraphs.

Traction motor refers to an electric motor providing the primary rotational torque of a machine, usually for conversion into linear motion (traction). Traction motors are used in electrically powered rail vehicles such as electric multiple units and electric locomotives, other electric vehicles such as electric milk floats, elevators, conveyors, and trolleybuses, as well as vehicles with electrical transmission systems such as diesel-electric, electric hybrid vehicles and battery electric vehicles [10]. Traction motors should meet a set of requirements [11]: high instant power, high power density, high torque at low speed, fast torque response, high efficiency over wide speed and torque ranges, high reliability and robustness, low cost.

Choice of DC Motor for Traction

Traditionally, traction motors were series-wound brushed DC motors, usually running on approximately 600 volts. The DC motor was the mainstay of electric traction drives on both electric and diesel-electric locomotives, street-cars/trams and diesel electric drilling rigs for many years. It consists of two parts, a rotating armature and fixed field windings surrounding the rotating armature mounted around a shaft. The fixed field windings consist of tightly wound coils of wire fitted inside the motor case. The armature is another set of coils wound round a central shaft and is connected to the field windings through "brushes" which are spring-loaded contacts pressing against an extension of the armature called the commutator. The commutator collects all the terminations of the armature coils

and distributes them in a circular pattern to allow the correct sequence of current flow. When the armature and the field windings are connected in series, the whole motor is referred to as "series-wound". A series-wound DC motor has a low resistance field and armature circuit. Because of this, when voltage is applied to it, the current is high due to Ohm's law. The advantage of high current is that the magnetic fields inside the motor are strong, producing high torque (turning force), so it is ideal for starting a train. The disadvantage is that the current flowing into the motor has to be limited, otherwise the supply could be overloaded or the motor and its cabling could be damaged. At best, the torque would exceed the adhesion and the driving wheels would slip. Traditionally, resistors were used to limit the initial current [12].

As the DC motor starts to turn, the interaction of the magnetic fields inside causes it to generate a voltage internally. This back EMF (electromagnetic force) opposes the applied voltage and the current that flows is governed by the difference between the two. As the motor speeds up, the internally generated voltage rises, the resultant EMF falls, less current passes through the motor and the torque drops. The motor naturally stops accelerating when the drag of the train matches the torque produced by the motors. To continue accelerating the train, series resistors are switched out step by step, each step increasing the effective voltage and thus the current and torque for a little bit longer until the motor catches up. This can be heard and felt in older DC trains as a series of clunks under the floor, each accompanied by a jerk of acceleration as the torque suddenly increases in response to the new surge of current. When no resistors are left in the circuit, full line voltage is applied directly to the motor. The train's speed remains constant at the point where the torque of the motor, governed by the effective voltage, equals the drag - sometimes referred to as balancing speed. If the train starts to climb an incline, the speed reduces because drag is greater than torque and the reduction in speed causes the back-EMF to fall and thus the effective voltage to rise - until the current through the motor produces enough torque to match the new drag [12].

If the train starts to descend a grade, the speed increases because the (reduced) drag is less than the torque. With increased speed, the internally generated back-EMF voltage rises, reducing the torque until the torque again balances the drag. On a sufficiently steep grade, the internally generated back EMF voltage may rise higher than the full line voltage. On such steep grades, the motor acts as a regenerative brake-the motor generates electric power, returns that power to the electric lines, and acts as a brake to prevent run-away acceleration down the grade. (On such a steep grade, adding resistors-or disconnecting the motor from the line entirely-would make the train go faster) [12].

On an electric train, the train driver originally had to control the cutting out of resistance manually, but by 1914, automatic acceleration was being used. This was achieved by an accelerating relay (often called a "notching relay") in the motor circuit which monitored the fall of current as each step of

resistance was cut out. All the driver had to do was select low, medium or full speed (called “shunt”, “series” and “parallel” from the way the motors were connected in the resistance circuit) and the automatic equipment would do the rest [12].

Choice of AC Induction Motor for Traction

The availability of high-powered semiconductors (such as thyristors and the IGBT) has now made practical the use of much simpler, higher-reliability AC induction motors known as asynchronous traction motors [13]. Synchronous AC motors are also occasionally used, as in the French TGV. It is now standard practice to provide one traction motor driving each axle through a gear drive. In the case of French TGV power cars, a motor mounted to the power car's frame drives each axle; a “tripod” drive allows a small amount of flexibility in the drive train allowing the bogies to pivot [14].

The use of induction motors (asynchronous motors) in urban transport instead of DC motors allows both the mono-motor driving on the axle and the driving of each wheel in order to meet the new requirements of the traction system, especially the low floor vehicle. The main advantage of the direct driving is to avoid the mechanical gearbox. The last one becomes soon worn due to the hard working conditions. The state-of-the-art light traction system of street cars (tramways, trolley lines, subway trains) consists of GTO or IGBT power inverter, feeding AC electric motors (cage induction, permanent magnet brushless or switched reluctance motors). An important feature of any traction motor is the rather long range of constant power. The both constant torque and constant power conditions on a wide speed range can be achieved through electronic control. On the other hand, the direct drive system (i.e. drive of axle or wheel without use of any gears) offers many benefits [15] that must be considered: no gear energy losses; no gear maintenance; no gear noise; oil-free drive system; reduced noise of the traction motor by rather low motor speed and by inverter feeding.

By special design, the induction motor proved to be a good economical solution, meeting the demands of power and speed for street car application [16,17]. In the paper [18] the authors state that the totally enclosed a.c. induction motor is the best choice for most variable-speed applications and for some applications the direct-drive a.c. induction motor is the better choice.

Choice of Permanent Magnet Motors for Traction

Nowadays, majority of the researchers consider that the Permanent Magnet Brushless Motors are more efficient, more compact, have better steady-state and dynamic performances at low speed and are excellent motors for direct drive traction applications [19,20]. Although permanent-magnet motors do not have the advantage of field strength control for speed

adjustment, they have a simpler design than the wound-field motor, and they are lighter and more efficient, having no copper losses in the field winding.

Because of the space required for the field structure of a wound field motor, the outside diameter of the motor is usually approximately twice that of the armature. If ceramic or rare-earth magnets are used in a permanent magnet motor, the high coercive force allows the magnet to be relatively thin. Hence the outside diameter of the motor can be considerably smaller than that of a comparable wound-field motor, and there will be an accompanying weight reduction. When anisotropic magnets are used, the preferred axis is oriented radially to coincide with the radial flux path. The return flux path is provided by a magnetic steel shell which forms the motor housing. The magnet segments are usually secured to the inside diameter of the housing with an adhesive [21].

Permanent magnet AC synchronous motors boasted as much as 93% efficiency while the more cost effective and popular DC Permanent Magnet motors have an efficiency of up to 90% [22].

Choice of Wheel Hub Motor for Traction

The wheel hub motor (also called wheel motor, wheel hub drive, hub motor or in-wheel motor) is an electric motor that is incorporated into the hub of a wheel and drives it directly. There are two basic categories of hub motors: direct drive and geared. Hub motor electromagnetic fields are supplied to the stationary windings of the motor. The outer part of the motor follows, or tries to follow, those fields, turning the attached wheel. In a brushed motor, energy is transferred by brushes contacting the rotating shaft of the motor. Energy is transferred in a brushless motor electronically, eliminating physical contact between stationary and moving parts. Although brushless motor technology is more expensive, most are more efficient and longer-lasting than brushed motor systems. Wheel hub motors have their greatest torque at startup, making them ideal for vehicles as they need the most torque at startup too. Their greatest torque occurs as the rotor first begins to turn, which is why wheel hub motors do not require an external gear box [23,20]. Wheel hub motors are increasingly common on electric bikes and electric scooters in some parts of the world, especially Asia.

OVERHEAD RAILWAY ELECTRIFICATION

The present invention demonstrates the adaptability of using wide power classification of overhead railway electrification as the power source.

The main advantage of overhead electrification is a higher power-to-weight ratio than forms of traction such as diesel or steam that generate power on board. Electricity enables faster acceleration and higher tractive effort on steep grades. On locomotives equipped with regenerative brakes, descending grades require very little use of air brakes and regenerative traction motors become generators sending current back into