Innovative American Maglev System

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ABSTRACT: This next generation magnetic levitation and propulsion system, derived from work done at NASA on magnetic bearings in the 1970's in now adapted to linear motion drives. The unique aspects of this system involves the fact that permanent magnets levitate the vehicle off a totally passive steel guideway without the need of an external power source except for minimal energy requirements for lateral control. Electromagnets modulate permanent magnet biasing to center the vehicle without contact while propulsion is supplied by a unique motor development allowing both the armature and the field source to be separate from the pole structure while utilizing the same guideway for both levitation and propulsion.

1 INTRODUCTION

Many people who view Maglev as a futuristic concept are unaware of its long history. Like all radical advancements it took a visionary to foresee an alternative to wheeled vehicles. Robert Goddard, better known as the father of American Rocketry, visualized and wrote a scientific paper as a college freshman on magnetically levitated trains in (horse and buggy days) 1905! Emile Bachelet, a French engineer, applied for a patent in 1910 for a magnetically levitated railroad car using solenoids at intervals along an electrified roadbed. Figure 1 depicts his levitated transmitting apparatus.

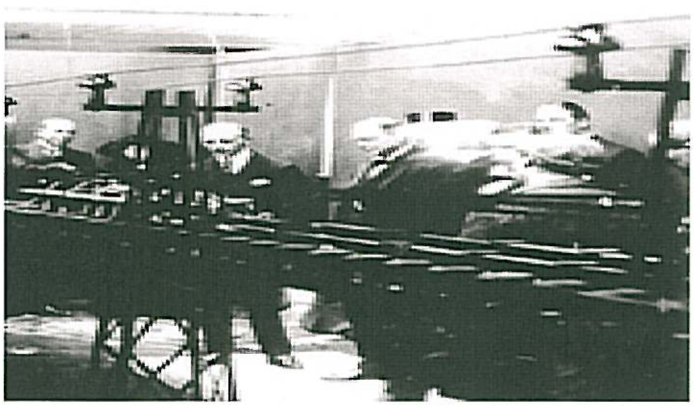

Figure 1. Emile Bachelet's levitated transmitting apparatus.

Dr. Jesse Beams at the University of Virginia built, in 1946, a magnetic suspension system (before the advent of solid state electronics) to levitate and rotate a steel bearing ball. He enclosed it in a vacuum, to further reduce drag, setting a record of over 2,000,000 RPM and performed many useful experiments with unobtainable surface speeds.

In the 1960's, NASA/Goddard Space Flight Center was a pioneer in the development of electronically commutated DC motors. One, of special interest here, was a large diameter flywheel with a steel many pole rim. The armature and field were both in a small stationary segment facing the rim. In an advancement of this concept as a Maglev propulsion device, proposed by this author and pending patent issuance, the parts are transposed; the multi-pole steel rim becomes the track and the armature and magnet assembly is the locomotive.

Dr. Strnat, doing Air Force research at the University of Dayton, developed the first practical rare-earth magnets, Samarium Cobalt, making possible an order of magnitude size, weight, and power reduction in electromagnetic devices in 1966.

In the 1970's, NASA/Goddard focused on magnetically suspending non-contacting rotating devices for long-life attitude control systems. One configuration, still in use, utilizes a single rare-earth permanent magnet for passive axial suspension which also biased the radial servo control of the flywheel. Upon examination one can see how this is applied to levitation and guidance of our vehicle – better seen in Figure 2 by inspection of a cross-section of this 3-inch diameter bearing.

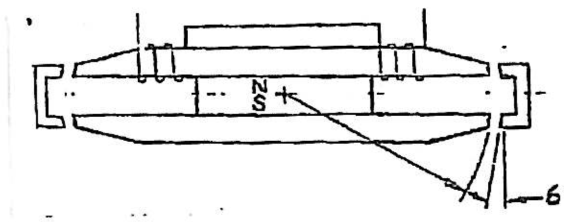

Figure 2. Cross-section of 3-inch diameter bearing.

You may not be aware of the Amateur Radio Satellite (OSCAR) passing overhead many times a day. It is a testimony to the practical reliability of its three magnetically suspended attitude control reaction wheels running continuously for the past several years.

There is another feature of our system, simplifying the complexity of most other maglev systems, in that we have combined the propulsion, levitation, and guidance, using the same magnetic flux, into a unified electromagnetic structure bridging the airgap separating the vehicle and the region of the track below it. However, I am getting ahead of myself. This will all become clearer with the function-by-function more detailed description of the system which follows, but we would like to point out that history shows that this is a truly American system from its very beginning, in its entire evolution, hopefully now in its next generation.

2 TECHNOLOGY DESCRIPTION

The system we are going to describe is truly unique. It is unlike the well known German maglev system which reaches under the track to pull up or the Japanese method which uses superconducting magnets to push down. It is also different from some newly advanced maglev system which requires forward motion to levitate. Our close clearance gaps are vertical, allowing a much greater tolerance for loading, a less demanding and lower cost roadbed, and a softer ride. The suspension works from standstill to full speed; even with loss of power, a great safety advantage.

2.1 Propulsion

Non-contacting levitation rules out most conventional forms of propulsion. DC motors have been a clear choice for traction motor applications since the early days of electrified transportation, because of their high starting torque, high efficiency, and easy controllability driving and braking (during which energy can be recovered). Among brushless motors there is an unresolved nomenclature choice between self-synchronous AC and electronically commutated DC, which physically are very similar. I prefer the latter, the term tending to imply trapezoidal generated waveform, not requiring sinusoidal inputs to achieve low output ripple and capable of slightly higher output per unit volume and less electronic complexity. Motor experts argue both sides of the issue.

The linear motor is no different in operating principle than the familiar rotary machine, in fact, torque is only the summation of all the tangential force vectors, which in a linear motor are aligned in a straight line. This motor stands alone in that both the armature and field are on the same side of the airgap, often leading to the question "what moves?" This is easily answered because although the field magnet is located with the armature, its magnetic flux passes across the gap to the pole structure in the track where it energizes 'north' and 'south' poles beneath the vehicle. In linear form, this technique allows a totally passive guideway without the need for costly windings or even conductive material. The motor configuration splits the field into two parts, combining the magnet source with the armature on the vehicle, the other part, across the airgaps is a pole structure stretched out along the full length of the track.

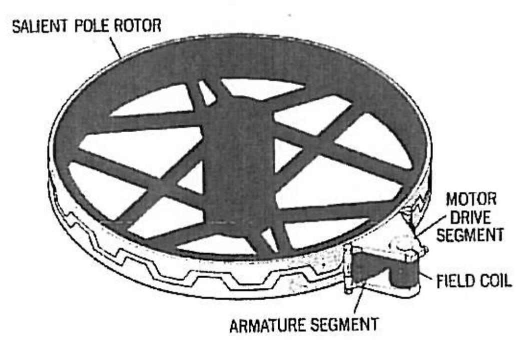

Figure 3. Multi-pole ring and motor drive.

Linear DC motors using this technology, previously developed for rotary motors, can perform the most efficient electrical to mechanical transformation. The armature, on board the vehicle, is completely conventional, typically 3 phase, with transverse conductors placed in slots in a short segment of laminations. The pole structure, of ordinary steel can be placed between the rails or on both sides of the track near the levitation and guidance gaps. This motor configuration splits the field into two parts, combining the magnet source with the armature on the vehicle. The second part is on the other side of the airgap. The magnetic flux passes across the gaps to the pole structure stretched out along the full length of the track, fully energizing those poles directly beneath it. Flux from those poles interacts with the armature electric currents producing thrust. The armature, on board the vehicle, is completely conventional, typically 3 phase, with transverse conductors placed in slots in a short segment of laminations. The pole spacing is set to match the conductor phase spacing and exactly the same relationship works to determine the conductor slot spacing. The armature is typically 3 phase and the developed power is related to total power less resistive losses and velocity dependent magnetic losses. Sensors observing the polarity of the region proximate to a conductor phase are used to drive a six switch, 3 phase power semiconductor bridge composed of MosFets and Diodes of appropriate power handling capacity. This revolutionary motor geometry makes it possible to use the best type of motor for traction purposes, the series DC motor with a totally passive guideway.

Three phase commutation reduces "force ripple" (analogous to torque ripple) to a reasonable level. To achieve more constant force, either of two approaches can be used; design the motor toward a sinusoidal flux waveform or a trapezoidal waveform. In the first case, a sinusoidal current waveform must be applied between commutation intervals, in the second, constant current is required, not only for 60 degrees "E", but varying linearly between plus and minus maxima. In neither case is perfection possible, the latter case does not require the complex current modulation/commutation circuitry and delivers higher output per unit weight.

The motor field flux is brought into the pole structure along continuous surfaces from which it flows laterally into polar elements equally spaced along the length of the guideway. When the armature laminations cover the pole, the flux, interacting with the armature currents moves axially to the opposite polarity poles. It returns via those alternate poles and the other continuous surface, from whence it passes across gaps to the opposite polarity side of its magnetic field source, completing the magnetic circuit.

2.2 Levitation

The fact that magnetic flux can be passed across airgaps without energy dissipation is at the heart of our unique suspension system; witness the magnets holding up your notes on your refrigerator. As in that example, the airgap (paper thickness), is vertical, but rather than relying on friction for support force, our method is more like a magnet holding to a narrow steel strip. One can move it relatively freely (neglecting friction) along the length of the strip but magnetic force resists moving it to the side past the edge. In like manner, our system uses the vertical component of the attractive force to overcome gravitational loads tending to misalign the two surfaces. This revolutionary suspension also has horizontal flux paths; between pairs of vertical surfaces.

The matched vertical widths of these mating surfaces resist being displaced vertically. This vertical (load-bearing) condition is maintained indefinitely, independent of speed and even without regard to the position of the rail in the dual gap, since the total magnetic circuit gap remains constant. The permanent magnets supply these forces passively, requiring no power.

The flux is divided equally between the two gaps which are oriented so that their forces oppose each other, essentially canceling their effect on the suspended body when the gaps are equalized by a servo. Fortunately, the vertical component is not canceled, in fact, the two add, keeping the suspension force nearly constant. The suspension force increases automatically with displacement so no power is required except for damping. The large attractive forces that can be produced by magnetic attraction are well known and are a function of the square of the gap flux density which can be increased beyond that of the permanent magnet by narrowing the width of magnetically "soft" steel alloys to reach saturation levels in excess of 20,000 gauss. In this system, these forces are primarily horizontal but a large fraction can be the vertical suspension component as the two surfaces move relative to each other under load. Ordinary permanent magnets supply the attractive forces keeping the vehicle suspended at any speed, including zero, when parked or being loaded. Passive, continuous, permanent magnet suspension not needing active control is a huge safety factor.

2.3 Guidance

Even though the load bearing suspension force is supplied by permanent magnets and requires no power, active control is required for guidance and to insure that the vehicle does not come in contact with the track while in operation, regardless of wind, track curvature, switching, and the unstable balance of large magnetic forces. The power required for this is minimized by dividing the flux into two symmetrical gaps as mentioned above but the forces are large, non-linear, requiring high peak power and fast response. Some forces are sometimes persistent like wind loads, in any case, it is desirable to minimize the power for these functions. A method which has been successfully used for other magnetic bearings applications is known as magnetic biasing. This takes advantage of the strong magnetic fields already existing in the above gaps to multiply the effectiveness of electromagnetic control flux. This occurs because the force is a function of the square of the total flux density in the gaps, and an increase of control flux in one gap and a decrease in the other yields a forceful linear output. Conventional maglev systems use power-hungry electromagnets to produce sufficient magnetic gap flux. Common gap sensors are needed to provide the basic control information of displacement, velocity, and sometimes higher order motion to a high power current amplifier for each element of a multi-segmented array along the side of the vehicle.

2.4 Integrated System

One of the key features of this new patent pending American maglev system is the integration of the electromagnetic structure for suspension, guidance, and propulsion into a unified electromagnetic structure, which is a weight, power, and dollar efficient way to proceed. What may or may not have been evident from the above discussion is the fact that these elements form a unified machine with a common magnetic field source and form the common magnetic field structural path for all three essential functions. This reduces magnetic losses and is a low cost highly efficient system. The intention is to reduce the leakage flux, saving size and weight and hopefully minimizing the force required for acceleration/deceleration and the power to accomplish the performance goals. Is is believed that this adaptation and advancement of the NASA developed technology can make a significant advancement in maglev systems performance and an equally drastic cost reduction. The cost per mile can be expected to drop precipitously by a design more tolerant of roadbed imperfections, a guideway requiring no power, made of the least expensive material and an energy recovery possibility by a bilateral drive and regenerative braking system, with the ability to construct and operate a quiet environmentally sound system on existing railroad rights of way. The cost savings benefits may be expanded by the use of light-weight carbon fiber vehicle construction in existing surplus auto manufacturing plants.

3 CONCLUSIONS

The benefits of a new, affordable high speed passenger rail service will benefit the whole nation as will environmentally sound quiet freight transport while reducing guideway and right of way costs.

a. The intercity traffic would increase with less compromise of long distance aircraft and highway traffic would decrease;

b. The delays in freight handling rail would disappear with the present limited passenger traffic having priority on single track constrictions of the existing rail lines; benefiting all industry and business in handling imports and exports;

c. The environmental improvement of rail transport over aircraft and auto would be noticeable;

d. New jobs in the manufacture, construction and soon in the operational elements would be created throughout the country; and

e. As drive-on drive-off facilities are developed in many cities and suburban areas commuting from desirable places to live to central workplaces without gas eating gridlock will become increasingly possible.