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KNOLLE MAGNETRANS, A MAGNETICALLY LEVITATED TRAIN SYSTEM

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1. INTRODUCTION

The Knolle Magnetrans (K-Mag) is a continuous transportation system featuring small cars in rapid succession, levitated by permanent magnets in repulsion and propelled by stationary linear induction motors (Figure 1). The vehicles' headway, speed, acceleration and deceleration are designed into the system and mechanically enforced. Passengers board dynamically and controls consist of a simple on-off relay. This paper summarizes the system design goals, describes the system components and discusses related environmental issues.

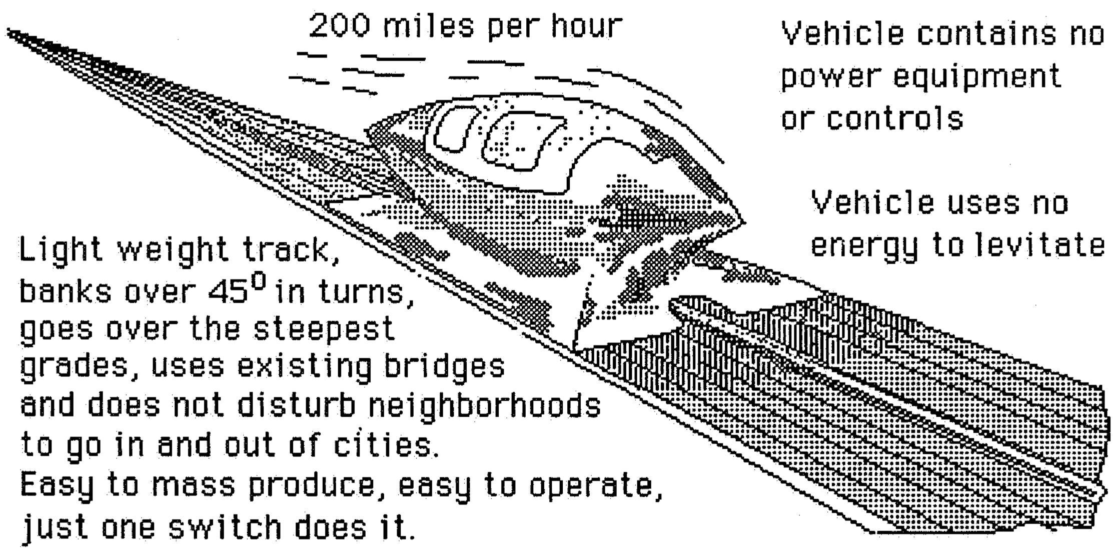

Figure 1: Knolle Magnetrans Perspective View

2. K-MAG DESIGN GOALS

As traffic congestion and urbanization increase, it becomes more and more difficult to find conventional solutions. Great progress is occuring in other fields, and it must be assumed that we can also advance in the field of transportation. Maglev technology can be the next evolutionary step.

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An ideal new ground transportation system should be pleasant, convenient, and passengers should have seats, comfort, privacy, and no long waits. Passengers should be moved between points of travel (door-to-door) at least as fast as automobiles for short distances, and, ideally, as fast as aircraft for long distances. In addition, a new ground transportation system should be profitable enough to attract private enterprise. The developer of the K-Mag has set himself the following goals:

a.Safety.	e.No waiting.	i.Quiet.
b.Business success.	f.Direct routing.	j.Non-polluting.
c.Rider satisfaction.	g.Minimize walking.	k.Flexible.
d.High speed.	h.Energy efficient.	l.Expandable.

3. PERMANENT MAGNETS IN REPULSION

Over 100 years ago, a maglev scientist by the name of Earnshaw experimented with permanent magnets in repulsion to suspend a vehicle over a track. The concept seemed feasible until all the iron horseshoe magnets died. Earnshaw's ideas came just a few decades too early; during his lifetime magnetic materials were not advanced enough to realize his invention. Today we have magnets that not only retain their full power indefinitely when repelled, but these new materials are 20 to 30 times more powerful than those Earnshaw used. As Table 1 shows, enormous progress was made in recent years in the discoveries of more powerful magnetic materials. Today, eleven times more powerful magnetic materials are available than just ten years ago. We successfully experimented with these new magnets by building a full-size prototype K-Mag; there is virtually no degradation in the magnets' strength after levitating a vehicle for over seven years to date.

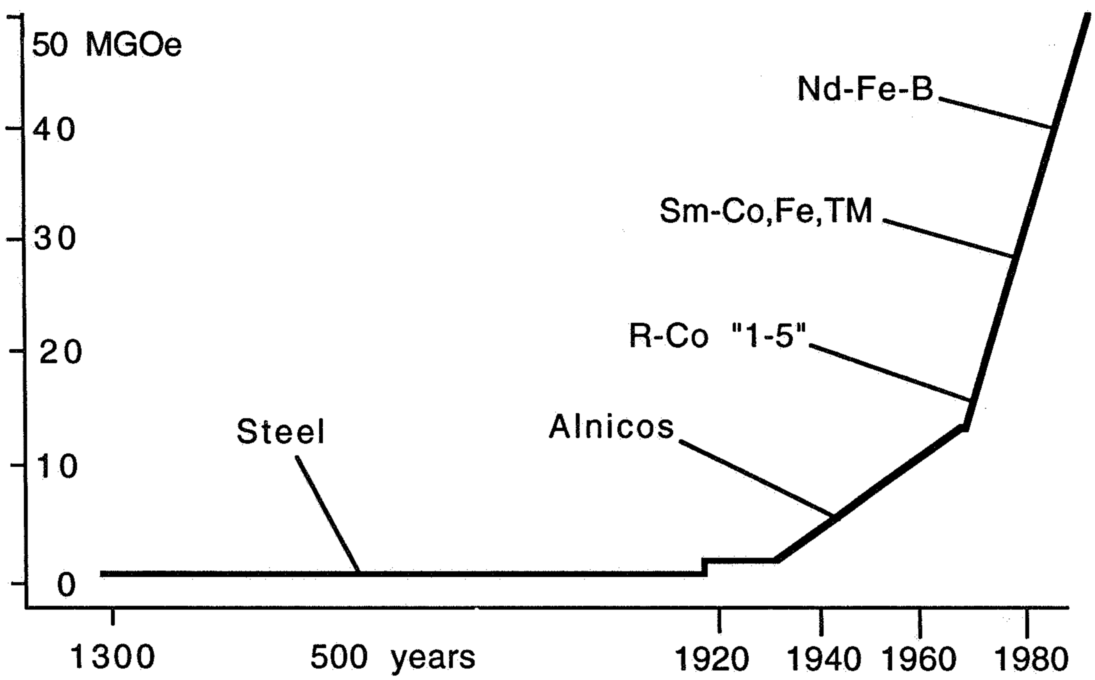

Table 1: History of Magnet Energy (BH)max

Figure 2 shows the basic components incorporated in the existing full size prototype. The rows of magnets cover the full length of the track and the full length of the car. Pairs of vertical dampers are located at the front and in the back. They are designed to minimize vertical oscillations due to track unevenness, wind and passenger movements. The lateral guides are located about one quarter of the distance from each end of the car. Their purpose is to hold the car magnets vertically above the track magnets or, when this is not possible as in curves, minimize lateral thrusts. The cars receive their propulsion and forward control from the chain by means of the car to chain attaching claw. The tubular chain in turn is driven by stationary constant speed linear motors, which may be as much as ten miles apart depending on terrain.

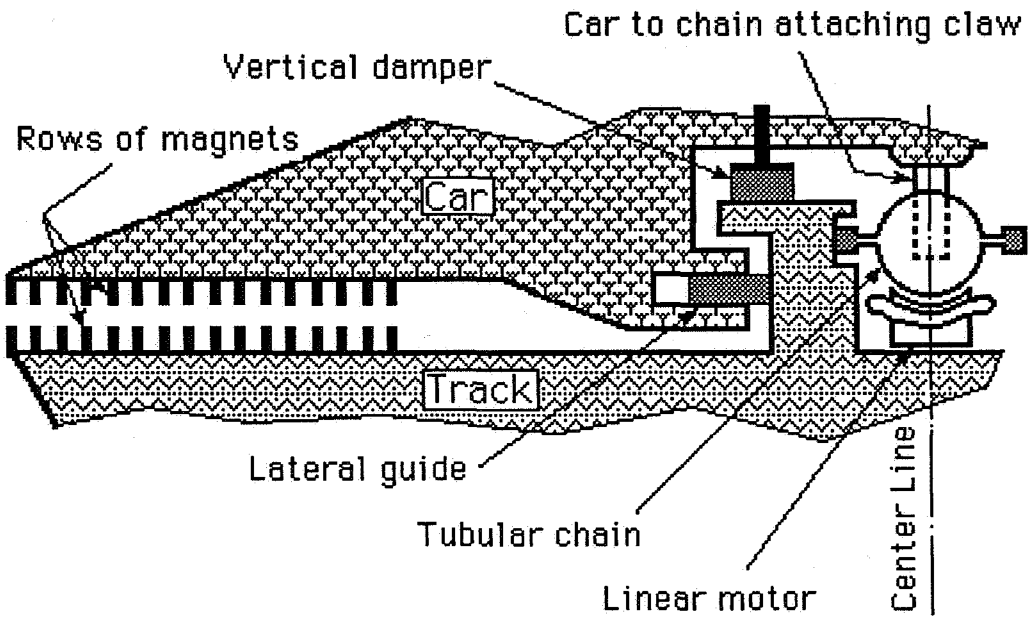

Figure 2: Car and Track Cross Section

The advantages of using permanent magnets in repulsion to levitate maglev vehicles are

- No energy is required to achieve the lift forces,
- The magnets are abundantly available at low cost,
- The magnets are easily installed,
- The magnets hold their lifting power virtually forever,
- Virtually no maintenance is required,
- The magnets are safe to operate, and
- Because the magnets are made of insulating material, there are no drag forces resulting from eddy currents.

4. LINEAR INDUCTION MOTOR (LIM) PROPULSION

The LIM idea dates back even further than the permanent magnet levitation concept, but hasn't made much progress in 150 years. A LIM is similar to a rotary electric motor but it is laid out flat. While a rotary motor has limits as to how many poles can fit into a circle, a LIM has no limit to length. However, it has the same major rotary motor shortcoming, and that is a lack of propulsion or thrust at partial or reduced speed. In rotary drives this problem is generally solved with reduction gears, but how do you attach a gear box to a LIM?

Figure 3 depicts how an adequate flux at full speed (thin line) changes its shape in the air gap to the dogleg line to generate a smaller thrust at reduced speed, just when the opposite is needed. The purpose of this drawing is to give the reader a basic simplistic understanding of the all-important electromagnetic flux flow in the air gap between stator and rotor. (Flux within the body of the stator or rotor has no effect on propulsion. Only the flux in the air gap does it.) The lack-of-thrust problem is actually much more complex. However, the K-Mag has solved this problem by mechanically assisting acceleration and hill climbing and by mechanically reusing kinetic and potential energy. The LIMs in the K-Mag run only at constant full speed and carry only a steady load.

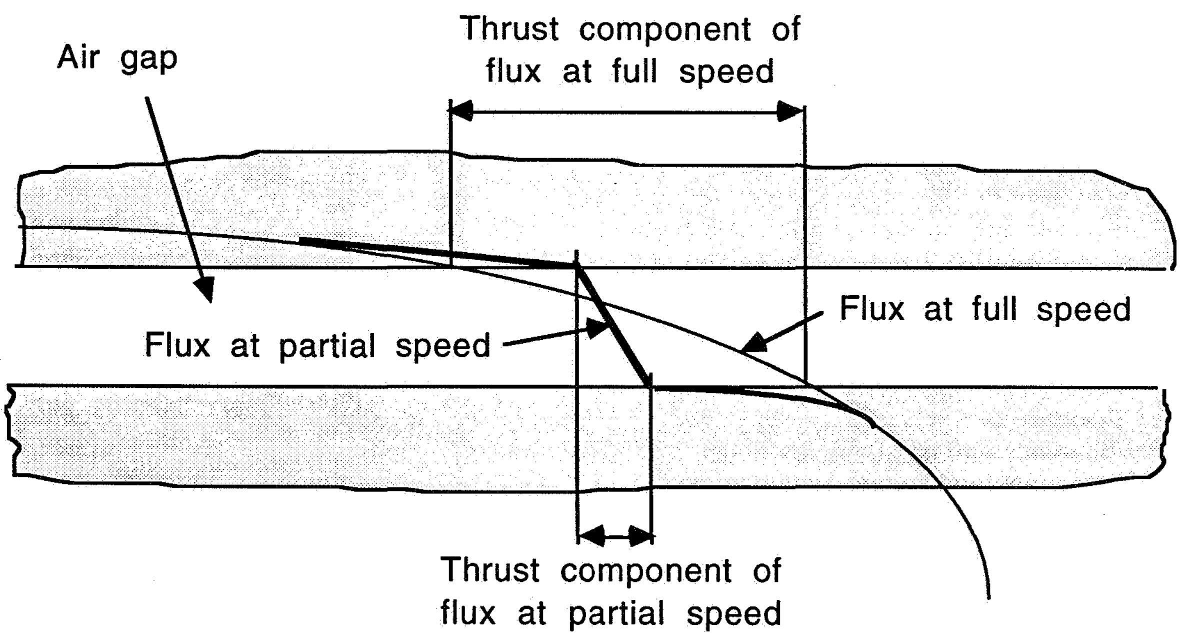

Figure 3: LIM's Loss of Thrust at Partial Speed

Other maglev developers, in Germany and Japan, build their LIMs enormously large to compensate for the lack of propulsion when accelerating and going uphill. The whole undersides and sides for the full length of their vehicles are covered with (LIM) motor windings and the tracks for their full length are also covered with (LIM) motor windings. The weight of the LIM hardware (wound primary and secondary) used on these systems is simply staggering. Figure 4 shows a chart which compares the weight of wound motor components of the German 'Transrapid' maglev with that of a conventional high speed train. It is based on a three million passengers per year proposal to link Las Vegas with Los Angeles. Also shown is how small the wound motor weight of the K-Mag would be for the same route.[1, 2]

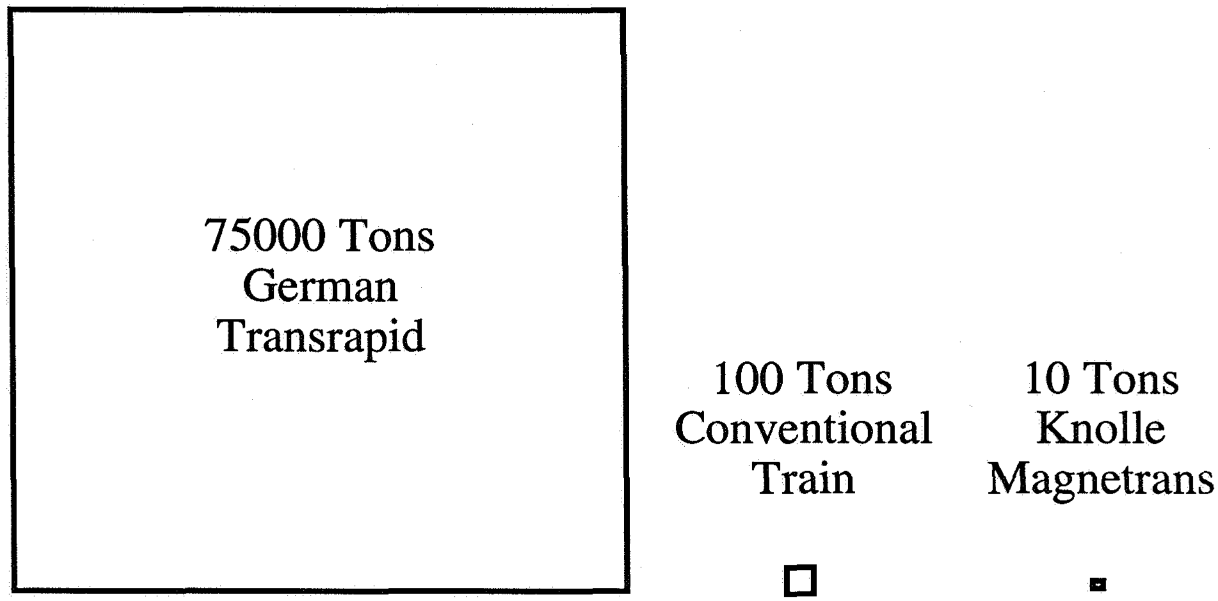

Figure 4: Motor Weight Comparison, Las Vegas to Los Angeles Proposed 230 Mile Route

The size of motor weight will naturally affect construction, operation and maintenance costs. The comparison also shows that maglev technology in the form of the K-Mag can also be a substantial improvement over conventional rail technology. Also interesting is that the Transrapid proposal calls for trains to follow each other at one hour intervals in each direction. Thus, their single track would be used less than one percent of the time. In contrast, the K-Mag track would be used every four seconds.

5. K-MAG - A CONTINUOUS TRANSPORTATION SYSTEM

Continuous transportation systems generally use evenly spaced cars physically connected to form closed loops driven by stationary motors at constant speed. This technology is not new. In 1908, I. Kiralfy obtained a U.S. Patent for a continuous system where passengers would step onto a moving belt and then transfer into small cars which were propelled in a continuous loop. Escalators, moving walkways, ski lifts, the Soulé system and the Disneyland people mover are all examples of successful continuous transportation systems. If a continuous system is moving at a high speed unsafe for passengers to board or exit, then a form of mechanical speed changer is used to assist at stations.

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[1] "Propulsion and Power Supply System of the Transrapid 06 Vehicle, Design and Test Results, Part I: Propulsion", International Conference on Maglev Transport '85, pages 75 - 82 (R. Friedrich, et al).

[2] Executive Summary, Las Vegas to Los Angeles High Speed/Super Speed Ground Transportation System Feasibility Study, January 27, 1983, The Budd Company, Technical Center.

The major advantages of most existing continuous systems are automation, simplicity, steep climbing ability and high capacity; for example, in escalators and ski lifts. The major disadvantages are the inability to vary capacity or to do switching, except that capacity could be reduced by turning the system off intermittently or by reducing speed during low use periods, as in the early morning hours, for instance.

The K-MAG is a continuous transportation system which uses permanent magnets in repulsion for suspension and constant speed stationary LIMs for propulsion. Figure 5 shows small cars that are permanently attached to a continuously moving endless long-linked chain. Chain guide rails along the track are used to guide the chain stretched out between stations, but force it to fold up in stations. This folding causes the chain and cars to slow down and come together in stations. Passengers board from moving platforms which run beside the cars. The chain is driven by stationary LIMs located at intervals along the way. The cars have flat bottoms covered with longitudinal rows of permanent magnets that repel themselves above identical magnets on the track. The speed differential between line speed and station speed is determined by the length of the chain links. If the links are 18 feet long, the system could run at 200 mph between stations and at escalator speed in stations.

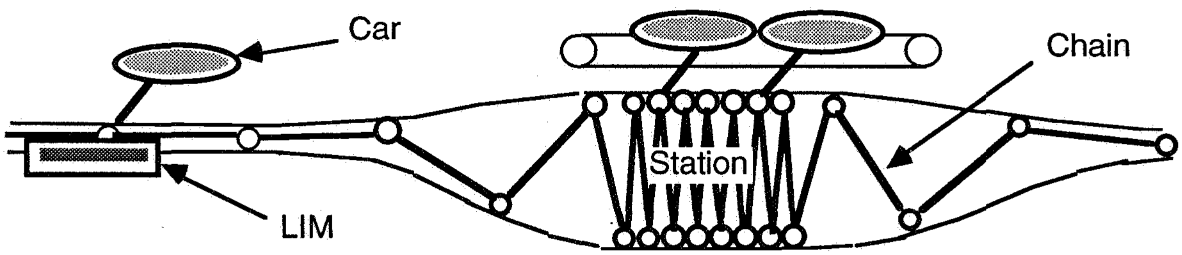

Figure 5: Chain Folding at Stations

6. ENERGY USE

	Average mph	Average pmpg
Japanese super-conducting maglev MLU-001	120[3]	2
German maglev Transrapid 006	120[4]	17
1960 Cadillac with 4 occupants	60	50
Boeing 737 200/300 coast-to-coast	600	100
Economy car with 4 occupants	60	120
Knolle Magnetrans at 25% occupancy	190	200

Table 2: Energy Use Comparison

Table 2 shows a comparison of energy use, expressed in passenger miles per gallon (pmpg), of several modes of transportation. Conversion calculations of electrical energy into gallons of fuel reflects power generation, distribution and converter efficiency. Even with assumed

[3] Same as Footnote 6.

[4] Pennsylvania High Speed Rail Feasibility Study, Executive Summary, Parsons Brinckerhoff/Gannett Fleming, February 1985, page 10, "Typical Trip Times".

occupancy of only 25% (75% empty seats), K-Mag greatly exceeds German and Japanese maglevs, both in energy efficiency and average speed. The latter is mainly due to K-Mag's ability to produce very high traction for acceleration and hill climbing as shown in Chart 1.[5, 6]

7. TRACTION

Traction is an important component of vehicle performance. It shows ability to accelerate and climb grades. It should be viewed together with the energy use shown in Table 2. A high energy use might be excused if it is accompanied by high performance. However, the reverse is the case with the German and Japanese maglevs. Not only do they use excessive amounts of energy, their traction is also the lowest. The mechanically enforced K-Mag, on the other hand, can accelerate at several Gs and climb very steep grades without reduction in speed. Chart 1 shows a traction comparison of several modes of transportation.

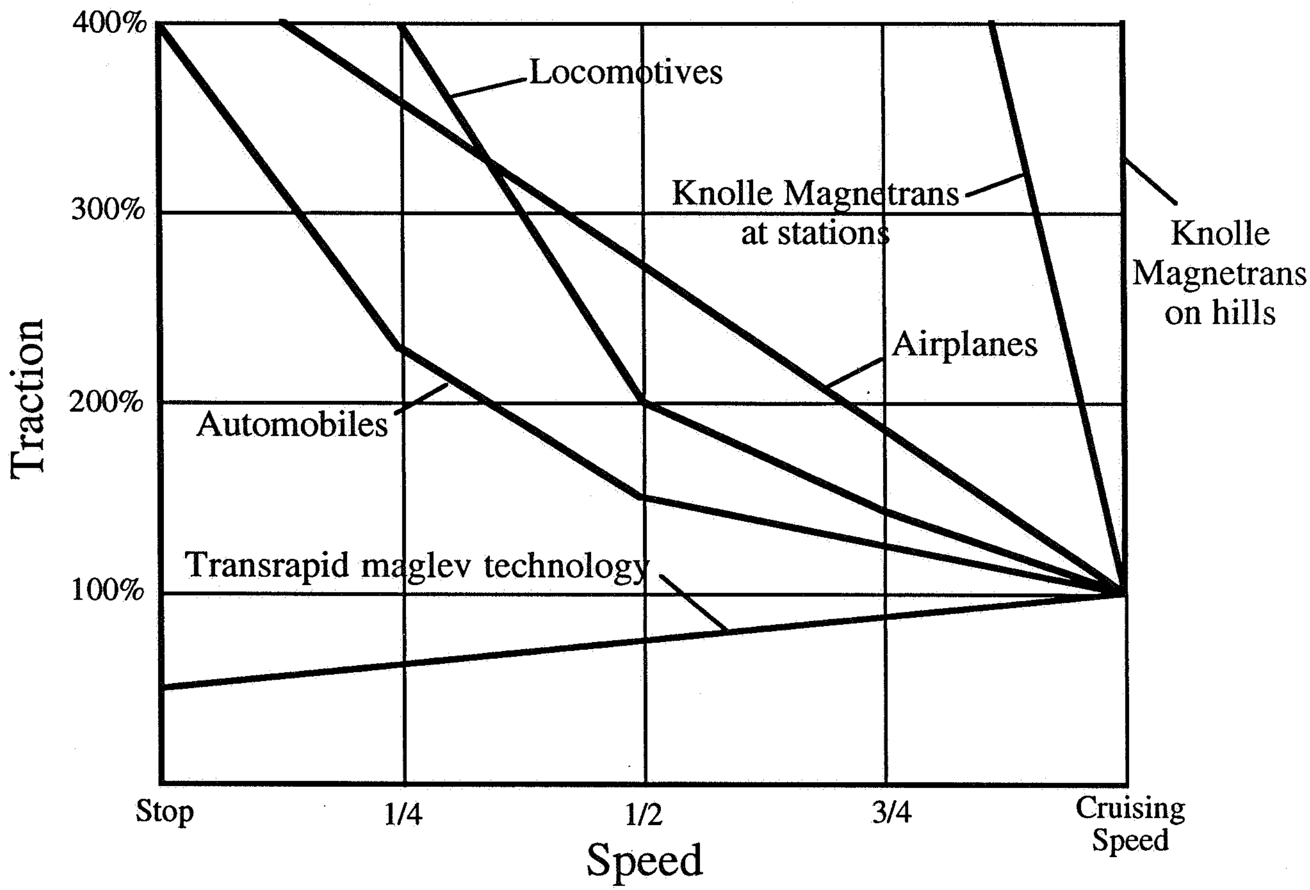

Chart 1: Comparison of Traction

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5 "The Vehicle Transrapid 06, Specification and Experience under Practical Conditions", International Conference on Maglev Transport '85, pages 115 -121 (J. Gaede).

6 "LSM Propulsion System of the Miyazaki Maglev Test Track", International Conference on Maglev Transport '85, pages 91 -98 (K. Nakamura, et al).

The traction of each mode was arbitrarily taken as 100% at cruising speed, and the additional capabilities calculated from recorded history. As an example, (based on general assumptions) the traction generated by an automobile at cruising speed of 60 mph could be increased by 50% at 30 mph and by over 100% at 15 mph through changing to lower gears.

8. ELECTROMAGNETIC RADIATION

Electromagnetic radiation is an unavoidable byproduct of maglev technology. However, the K-Mag has a safe level of electromagnetic radiation. Figure 6 shows a drawing of the measured (permanent magnet) radiation in the K-Mag, and Figure 7 is a drawing of the measured (dangerous low frequency) radiation around Japan's superconducting maglev MLU-001. (Low frequency radiation is about ten times as dangerous as permanent magnet generated radiation). The MLU-001 radiates over one hundred times the level which is presently considered safe by the Environmental Protection Agency.[7,8]

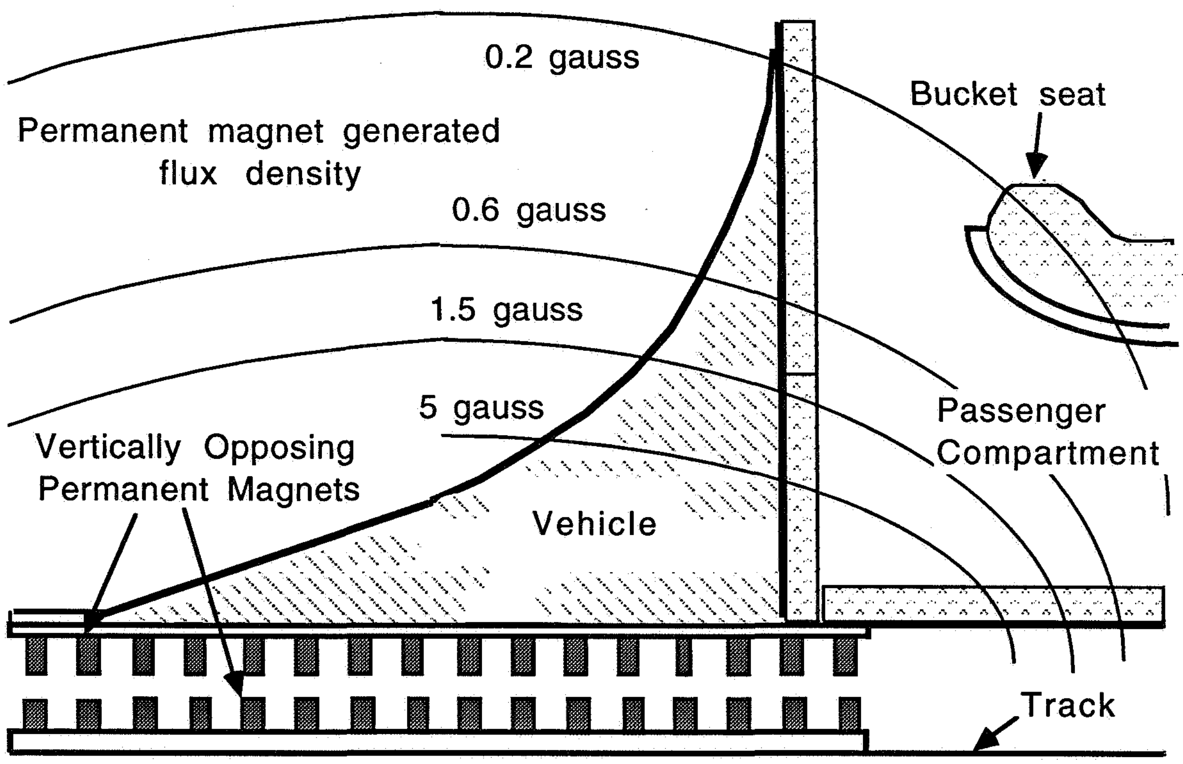

Figure 6: K-Mag's Safe Level of Electromagnetic Radiation

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7 " Magnetic Field Shielding for Electromagnetic Maglev Vehicles", International Conference on Maglev and Linear Drives, 1987, pages 53 - 66 (W. F. Hayes).

8 Competitive Request for Proposal Number, DTFR53-91-R-00021, "Maglev System Concept Definition", U. S. Department of Transportation, Federal Railroad Administration, February 22, 1991, page 13.

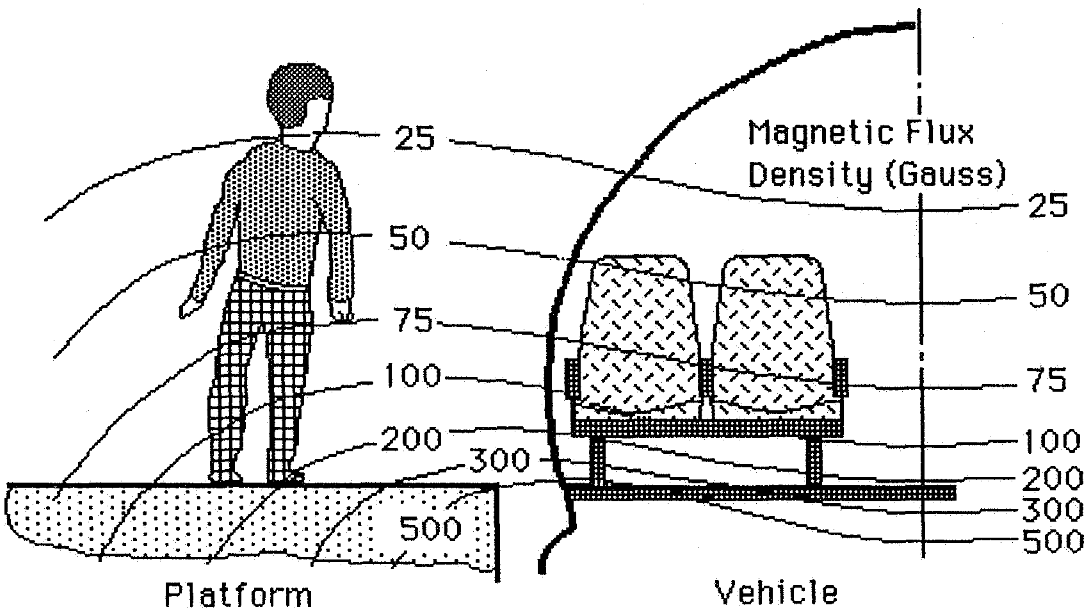

Figure 7: Dangerous Magnetic Radiation at Japan's MLU-001

9. OTHER INFORMATION AND EXHIBITS

A copyrighted technical description of the K-Mag is contained in the ASCE publication "Automated People Movers II" (References 1). Further information is also contained in "White Paper on High Performance High Efficiency Maglev, E. G. Knolle" submitted to the U.S. Department of Energy, 15 June 1990 (Reference 2). Available from the author are several short articles on specific aspects of maglev technology. Presently before the Federal Railroad Administration is a proposed study contract "Knolle Magnetrans, Maglev System Concept Definition Technical Proposal" dated April 22, 1991 (Footnote 8). Additionally, a full size K-Mag prototype vehicle on a short section of track is available for inspection in California, as well as full size test components. The concept of the chain folding mechanism is patented (Footnote 3).

10. CONCLUSION

The K-Mag concept shows that magnetic levitation can be accomplished at low cost without use of energy with permanent magnets in repulsion. The absence of on board energy requirement also means absence of heavy on board electrical equipment, which makes vehicles very light. The lack of traction by standard LIMs during acceleration and hill climbing is solved by the K-Mag with mechanical headway controls. The LIMs in the K-Mag are used efficiently at constant speed under constant load. Kinetic and potential energy is mechanically recovered. The result is extremely high energy efficiency while providing superior and safe service (low electromagnetic radiation).

Suitable for both short and long distances, the K-Mag technology is now ready for full size testing. Plans, cost estimates and a feasibility study have been made for a five mile long high speed oval test track. Government assistance would be appreciated. However, new venture risks might be better assumed by private enterprise.

10. REFERENCES

1. 1989 Ernst G. Knolle, "Knolle Magnetrans High Speed Maglev People Mover", *Automated People Movers II*, Library of Congress Catalog Card No: 89-17833, ISBN 0-87262-73.1-4, pp 871-880.

2. 1990 Ernst G. Knolle, "White Paper on High Performance High Efficiency Maglev", submitted to U.S. Department of Energy, 15 June 1990.

3. 1969 U.S. Patent No.3,320,903, Re. 26673, 1969, Articulated Train System, Ernst G. Knolle, inventor.