THE WOLFSON MAGLEV PROJECT

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ABSTRACT

The philosophy behind the Wolfson Maglev Project at Warwick University is stated, and details of major elements of hardware are given. Levitation and propulsion techniques, cryostat and chassis designs that will be incorporated in the final passenger carrying vehicles are discussed.

INTRODUCTION

In the design of new systems for inter-city travel speed and efficiency combined with safety and economy are paramount factors. How far the orthodox wheel-on-rail principle can be extended is still an open question but beyond about 250 Km/h the technical and safety problems, and track and maintenance costs multiply rapidly. For these and other reasons there is now a world-wide interest in the development of high-speed non-contact systems. In particular, in Great Britain, magnetic suspension and propulsion is being examined by a number of Groups.

U.K. RESEARCH ON MAGNETIC LEVITATION

At Sussex University the electromagnetic attraction system is being developed for low-speed urban transport while at Warwick University, the electrodynamic repulsion or Maglev system, for high-speed intercity applications, is being studied. Both of these projects are supported by the Wolfson Foundation. At Imperial College in London an a.c. induction method using the transverse flux linear induction motor for both propulsion and levitation is being developed.

WOLFSON PROJECT

The Wolfson project at Warwick which is the subject of this paper has been set up with the primary object of design and constructing a model test vehicle to demonstrate the feasibility of the Maglev principles and to highlight some of the engineering problems to which a full-scale revenue vehicle may be subjected. The project has funding for five years from 1973. To allow for test speeds up to 250 km/h a straight, level track, 600 m long and 1 m wide, is being designed for construction on the University site.

The test vehicle, 3 m by 1 m, weighing 600 kg, is being designed with accommodation for two passengers and the major elements of hardware, such as the vehicle body, cryostat and superconducting coil assembly, are in the early stages of design. An important consideration in the design aspects has been the maximum flexibility in the configuration of the levitation, the guidance and the propulsion elements. The laboratory model studies which have been undertaken at Warwick(1) are being extended in order to assess the theoretical predictions of this system.

For the preliminary vehicle tests, a towed trolley is being designed and in the following sections some of the essential features will be discussed together with the design philosophy of the superconducting magnets, the linear motor propulsion, and ideas for combined lift, guidance and propulsion.

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MAGNETS AND CRYOSTAT

As will become clear from the following sections, no final decision has been taken on the magnet arrangement. Nevertheless, a number of preliminary studies of magnetic optimisation have been made. For square coils, and a nominal levitation height of 0.2 m, the quantity of superconductor needed to lift the specified vehicle is a minimum for coils 0.8 x 0.8 m. A more complete optimisation, which would include track costs, would result in smaller coils (in rough terms the track conductor width need not exceed the coil width plus twice the levitation height. For the Wolfson test track as presently envisaged the track conductor is about 25 times as expensive as the superconducting coils, and the economic advantages of some reduction in coil width are obvious).

However, larger coils with correspondingly lower field strength do have some advantages, such as:

(1) the mechanical stress in the windings is relatively low
(2) the ripple fields, and hence hysteretic losses in the superconductor are low
(3) it may be possible to dispense with a liquid helium bath, and mount the coils directly onto a surface cooled by contact with the helium reservoir.

In view of the uncertainties and to allow for maximum flexibility the cryostat is designed as one large vacuum box, (Fig. 1) fabricated in aluminium and containing a liquid-nitrogen cooled shield. This enables the entire inner space to be utilized as required (the illustration shows the 2 x 0.8 m square coils in tandem). The main liquid helium reservoir of 30 ℓ is contained in two cylindrical vessels; by allowing the pressure to rise these will accommodate the boil-off for several hours operation. Vertical support is by fibreglass/epoxy tubes, with longitudinal and lateral forces being taken by steel wires. To withstand the vacuum loadings without introducing support structures into the coil space the top and bottom surfaces are curved, and hence the aluminium guideway will be laid as a shallow V.

PROPULSION

A major part of the Wolfson project is the development of a linear electric drive to be combined if possible with the levitation. Since the research is directed to a wide gap, high speed, system induction machines are rejected for the usual reasons.

The Linear synchronous motor (LSM), on the other hand, is compatible with the larger track-vehicle clearance of the maglev vehicle and can be designed to have acceptable efficiency and, with suitable compensation, power factor also. However, for starting and for operation at variable speed, frequency conversion equipment is required, which necessarily adds to the cost and complexity of the system.

An alternative with inherently good starting characteristics is a linear commutator machine, the rotary equivalent of which is well established in traction practice for precisely this reason. A powered track winding not unlike that of an LSM would be used; now however only those loops interacting with the vehicle magnets would be switched on by means of a commutator operated from the vehicle. In this manner the travelling magnetic wave on the track is automatic-

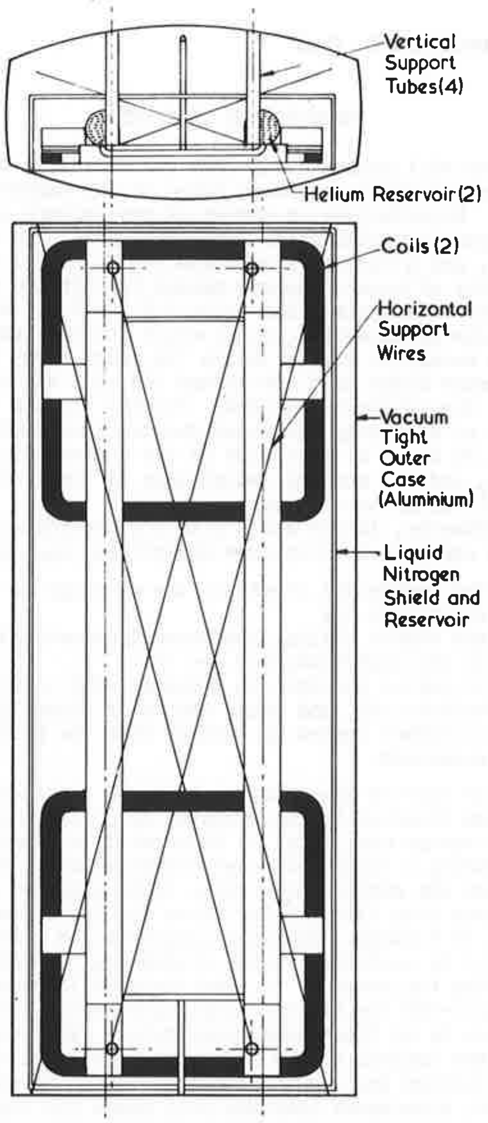

Fig. 1. Cryostat

ally kept in synchronism with the vehicle, irrespective of the latter's speed. Commutation would be controlled by thyristors on the trackside operated by signals (e.g. magnetic) transmitted from the vehicle, and switched off again by supplying the track with power frequency a.c. - the thyristors thus have the dual role of commutator and rectifier. Because of the low duty cycle the thyristors could be considerably overrated, and hence their cost minimised to a level comparable with the track conductor costs or less. Such a system would be of especial interest near stations, where the vehicle must be accelerated and decelerated. A scheme using a switched track, which may be similar to this, has been proposed by Atherton(2).

A laboratory model, with twelve coil positions around the cylindrical surface of a 0.8 m diameter drum, and a fixed permanent magnet to represent the vehicle, has been built. Switching is by means of a commutator, though it is proposed to use thyristors at a later stage. Although this model has demonstrated the principles of the scheme, there are as yet insufficient quantitative results for publication.

Parallel theoretical studies are pointing the way to other developments, arising from the fact that as well as thrust a practical linear machine must produce a lift force, and also lateral forces if the vehicle is displaced sideways. This is particularly noticeable in the Wolfson project where, because of the short track length and consequent high accelerations, the design thrust equals the vehicle weight.

The results of preliminary inductance calculations on a number of possible machine configurations indicate that, operated as a synchronous machine, stability in the longitudinal direction implies that at least one of the lift and guidance forces is negative; operated as a LCM, on the other hand, it appears to be possible to obtain thrust lift and guidance simultaneously, though the stability then depends on the proper functioning of the power system

LEVITATION AND GUIDANCE

The theory of levitation has been exhaustively discussed in the literature. The Wolfson model is somewhat atypical, in that levitation is desirable at lower speeds than usual, and the high design acceleration makes the low speed drag peak relatively less important. Coupled with the need to consider propulsion as well, provisional designs assume coils with rather low length to width ratios of between 1 and 2.

Methods of guidance in which additional, usually vertical, conducting strips are used are technically feasible, but introduce difficulties in the design of switches and in the use of termini and associated tracks in common with existing transport modes. Moreover, the guidance significantly increases the track conductor costs above those needed for levitation, and the trough-like contour provides a trap for debris.

Since guidance can also be achieved by omitting conducting strips, some of these objections can be overcome by a flat guideway design. A possible scheme for the Wolfson vehicle is shown in Fig. 2, together with curves (derived from inductance measurements on a model) of lift and guidance forces. The maximum useful lateral displacement in this case is of the order of the levitation height. Other models have been made which show that, in a revenue vehicle with magnets along each side, the guideway could be of similar form (the the strips being set rather wider apart than the coils) or could consist of double strips for each row of coils. As in all these cases the lift is reduced compared with an infinite ground plane, the superconductor cost is increased (typically by a factor of two), but this is more than offset by savings in track costs. However, for a complete evaluation it will be necessary to study the drag forces also. As far as stability is concerned the coupling between lift and guidance suggests difficulties may be encountered, as is indeed the case, for example, in V guideways (1, 3); on the other hand models levitated by a.c. excited coils, or by permanent magnets over an aluminium drum slit to represent the guideway, have shown stability. It is hoped to present a more detailed report at a later date. The scheme is in principle similar to that of the M.I.T. group (4,5) who have demonstrated stable guideway designs.

TRACK

The limitations imposed on the track design are principally constructional simplicity and cost, this consequently influencing most other mechanical aspects of the design. The track will consist of aluminium guideway conductors fixed to a continuous flat, fibre-reinforced concrete bed, 75 mm thick and 1.3 m wide, supported on aluminium structural sections resting on concrete piers as shown in Fig. 3. The fibre-reinforcing and aluminium supports are essential for eliminating ferromagnetic interference. The track will be laid on the University campus and initially will

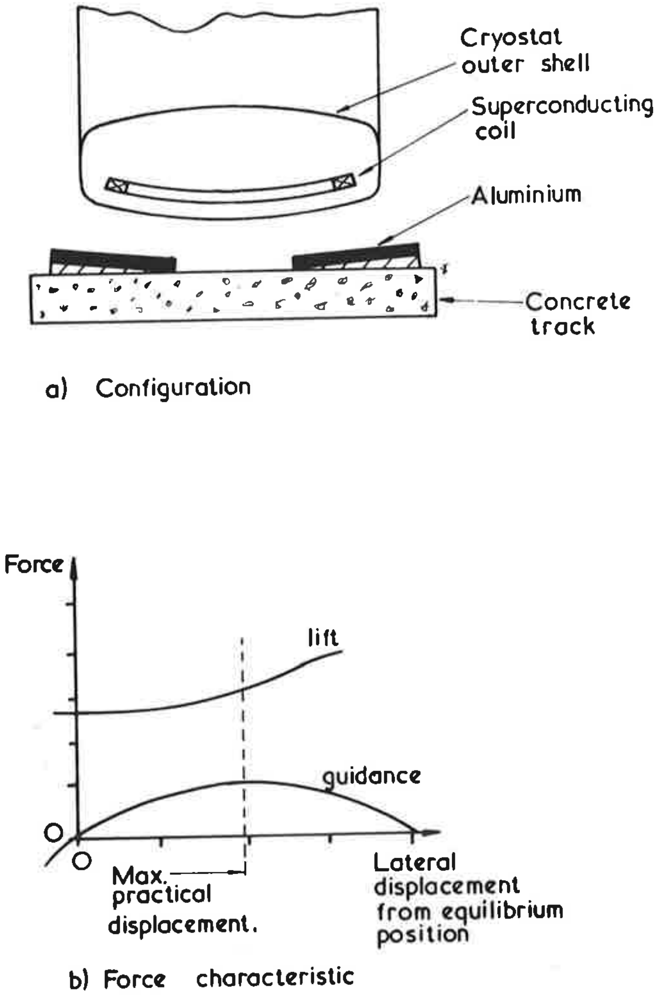

Fig. 2. Flat Guideway

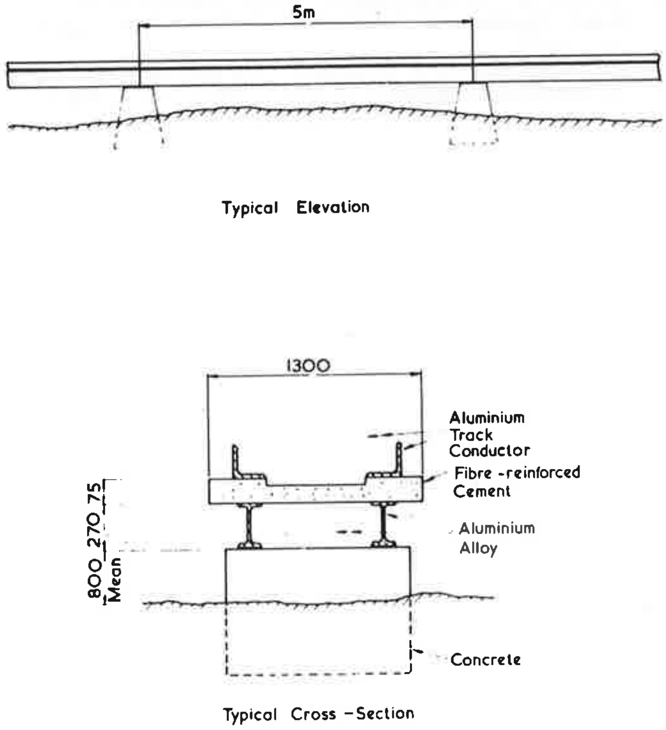

Fig. 3. Proposed Test Track

consist of a straight run 600 m long. It is hoped to extend this later to 900 m length including a curved section of 0.5 Km radius. An emergency braking area will be incorporated into the end of the track and the system will require trackside facilities for power generation, helium storage and recovery, and repair work.

During the initial testing, while the electromagnetic propulsion is under development the vehicle propulsion and braking will be derived mechanically from an external source acting directly on a trolley moving with the vehicle. This will ensure that only longitudinal accelerations are imposed on the vehicle. The winch and cable system as used extensively to launch gliders can be modified to meet the requirements of controlled acceleration and retardation of the vehicles. Alternative propulsion forms were investigated and rejected; the air pressure system on account of its high cost, and the trolley-mounted engine because of control problems. The trolley, apart from applying the longitudinal acceleration to the vehicle, will also serve to restrain the vehicle from extensive pitch, roll, or yaw motions, and excessive deviations in lateral or vertical position. It must also limit particular motions or combinations of motion as desired while remaining firmly on the track and be capable of supporting the static weight of the vehicle. Aerodynamic interference between the trolley and the vehicle must if possible be avoided. The trolley is being designed for the L-shaped guideway shown in Fig. 3 and consists of a front and rear subframe supporting the wheels connected by a tube each side acting as a drag link. The loads imposed on the trolley are the static weight of the vehicle, thrust and braking forces from the external system, inertial and magnetic drag forces, and aerodynamic forces which are principally side force and yawing moment.

A system of linear bearings and a spherical bearing on the front subframe allow the vehicle to pitch, heave, yaw, roll and sideslip with the applied force acting longitudinally. Ideally the force needs to be applied at the centre of thrust expected for the electromagnetic propulsion but the nearest location possible in this design is at the point where a line through the magnet centres meets the front face of the cryostat. Control on extreme vehicle motions is provided by limiting the movement of a spike from the trailing edge of the cryostat where it passes through the subframe.

The external shape of the vehicle has beed designed by M. Wilson, of the Lanchester Polytechnic, Coventry, subject to constraints of cryostat size and passenger space, and aerodynamic consideration. By shaping certain areas, especially the underside of the base and the upper rear longitudinal edges, an attempt has been made to create controlled air flow separation, and hence limit sensitivity to yaw and pitch.

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