THE PERFORMANCE OF INDUCTION LEVITATORS

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Abstract Induction levitators are devices which produce repulsion as a result of the interaction between excited coils and the eddy currents which they induce in some other conducting member. Machines such as this have been proposed as the levitation mechanism for contactless transport systems (MAGLEV)[1,2], or as magnetic bearings [3]. In this paper we present studies of small laboratory models of induction levitators (Fig 1). Measurements are compared with calculated values obtained by a finite element analysis. The secondary consists of a conducting plate which could be backed by iron if required, and detailed measurements and calculations are presented which illustrate the effects of the shape and size of the secondary on the forces (lift and lateral) and the power factor. A levitation system for a 50 tonne MAGLEV vehicle is then investigated computationally.

INTRODUCTION

A small model (38 cm long) of an induction levitator is shown in Fig 1. The armature consists of a laminated 'u' shaped iron yoke, around the limbs of which are wound the two primary excitation coils carrying single phase 50Hz current. Eddy currents are induced in the conducting secondary which produce a force of repulsion between secondary and yoke. A lateral stabilising force can also be produced. Those two forces depend not only on the configuration of the yoke, but also on such secondary parameters as the width, thickness of conducting plate and whether or not the plate is backed by iron.

An investigation into the nature of those forces is described here. A 2-D finite element program was verified using the small models, and then used in a design study of a levitation system for a 50 tonne MAGLEV vehicle.

FINITE ELEMENT MODEL

In all the experiments described the iron flux density was kept low, so that magnetic linearity is applicable.

A mathematical model of the machine was adopted in which all the current flow is in the z direction (Fig 1). This idealisation would be correct for an infinitely long machine and was found to be reasonable in the present case as measurements obtained from 10cm, 38cm and cylindrical (radius 15cm, representing the infinitely long case) machines were very similar. Fields can therefore be described in terms of the magnetic vector potential A_z:

$$\frac{1}{\mu}\frac{\partial^2 A_z}{\partial x^2} + \frac{1}{\mu}\frac{\partial^2 A_z}{\partial y^2} = \sigma j\omega A_z - J_s \qquad \ldots (1)$$

in which J_s is the excitation current density and σ is the conductivity of the secondary plate.

This equation is solved in the usual way, by discretizing the problem region into finite elements and applying the Galerkin weighted residual technique [4].

EXPERIMENTAL AND CALCULATED RESULTS

A computer drawn flux plot for the levitator at one instant in time is shown in Fig 2. Typical results for normal and lateral forces as well as power factor versus secondary displacement are shown in Fig 3 and are summarised in Table 1. Generally, it may be observed that thicker conducting plates improve lift and reduce lateral stability, while secondary backing iron improves power factor.

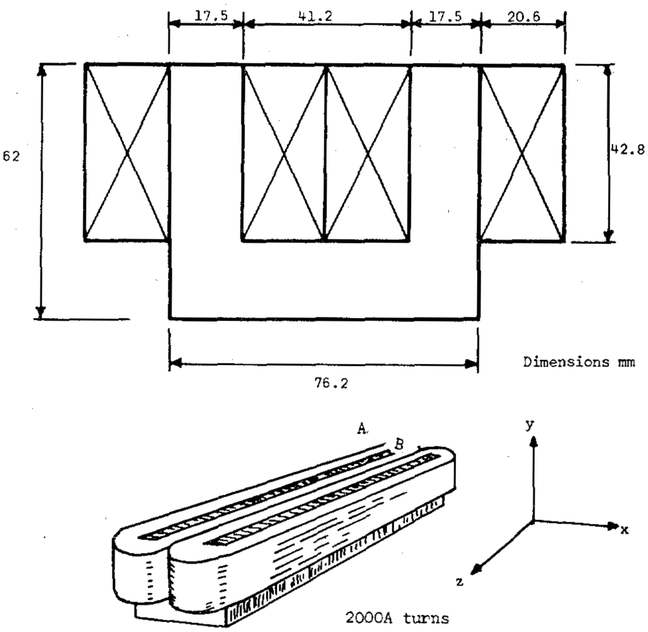

Fig 1 Single phase levitator details

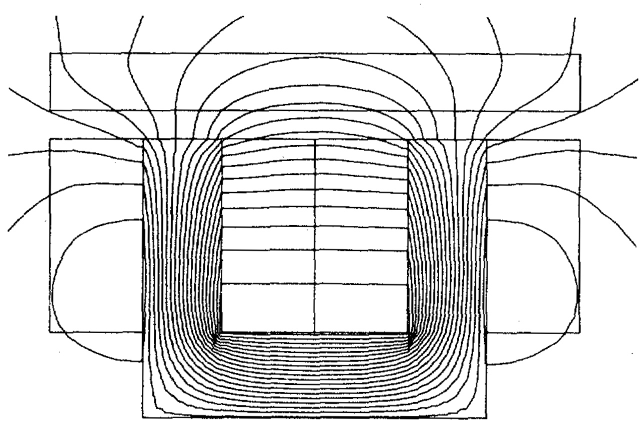

Fig 2 Contours of A at one instant in time

track cross-section	track aluminium dimensions (mm)	track iron dimensions (mm)	maximum lateral force (N)	lift force at equilibrium (N)	power factor at equilibrium
	6.35x117.5	none	10	38	.27
	12.7x117.5	none	6	54	.27
	6.35x117.5	6.35x79.4	17	22	.37
	12.7x117.5	6.35x79.4	8	58	.29
	6.35x117.5	6.35x79.4	18	29	.44
	6.35x117.5	6.35x117.5	25	32	.44

Table 1 Series connected single phase levitator

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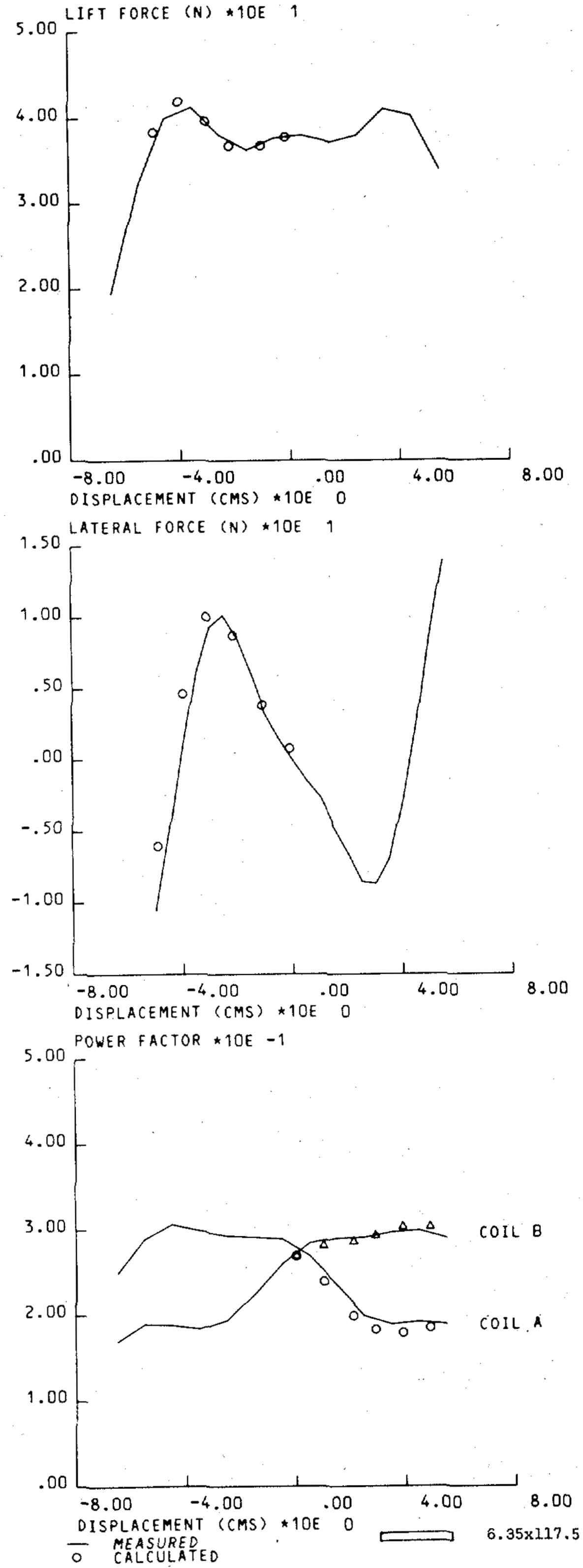

Fig 3 Characteristics of a small levitator (first on Table 1)

DESIGN STUDY OF TWO SINGLE PHASE LEVITATORS FOR 50 TONNE VEHICLES

The finite element model which was verified using the small laboratory machines was used to design two different single phase levitators, in order to assess the usefulness of magnetic river devices in levitating a 50 tonne vehicle.

Cross-sections of the two machines are shown in Fig 4. Stator A has a lamination 'window' height to width ratio of 7cm : 22cm. Stator B, by comparison, is wide and low, the corresponding ratio being 5cm : 36cm.

Different stator cross-sections were tried in this way in order to assess whether stator leakage flux (apparent in Fig 2) was reduced by lowering this ratio. The stator current densities were fixed at $6A/mm^2$, which was thought to be a reasonable value for forced air cooling.

In Fig 5 is shown the lift against displacement curves for the two machines at constant current and 2cm airgap. Fig 6 displays the corresponding curve for lateral force.

The results of calculations on heave damping [5] appear to indicate that active control of the height of a vehicle levitated in this way is essential on the grounds of ride quality, very little inherent damping of vertical motion being apparent. It is therefore

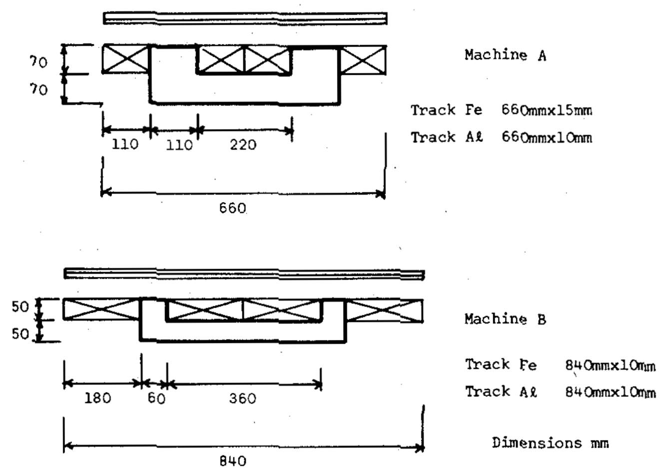

Fig 4 Cross-sections of machines for 50 tonne vehicle

assumed that the input current is controlled to maintain a constant airgap, and that the required maximum lateral restoring force will be around 40% of the vehicle weight. This means that the lift curves of Fig 5 have to be scaled to produce a constant lift at constant airgap, for each displacement position. Since this is carried out by changing the machine input current, the lateral forces at each position will also be scaled by the same factors, resulting in the curves of Fig 7.

Table 2 summarises a number of important characteristics for the machines. The reactive power requirement for both the central position and the position at which the lateral force is equal to 40% of the weight of the vehicle is shown. The reactive power requirement at the latter position, of maximum displacement, is higher than the reactive power required at the central position, so this power demand sets the size of synchronous capacitor which would be needed to raise the power factor of the device to unity. The weight of synchronous capacitors is assumed to be 2.4 tonne per MVAr, so that those weights are also given on the table.

Total length of stator (m)	MVAr		Real MVA excluding stator I^2R loss		Weight of synch cap for power factor = 1.0(tonne)	Stator weight (tonne)
	Track central	Track at max lateral displacement	Track central	Track at max displacement		
A 20	17	17.2	3.3	3.4	7.2	10.4
B 20	13.6	21.4	3.0	5.2	8.9	8.4

Table 2 Characteristics of the 50 tonne vehicle

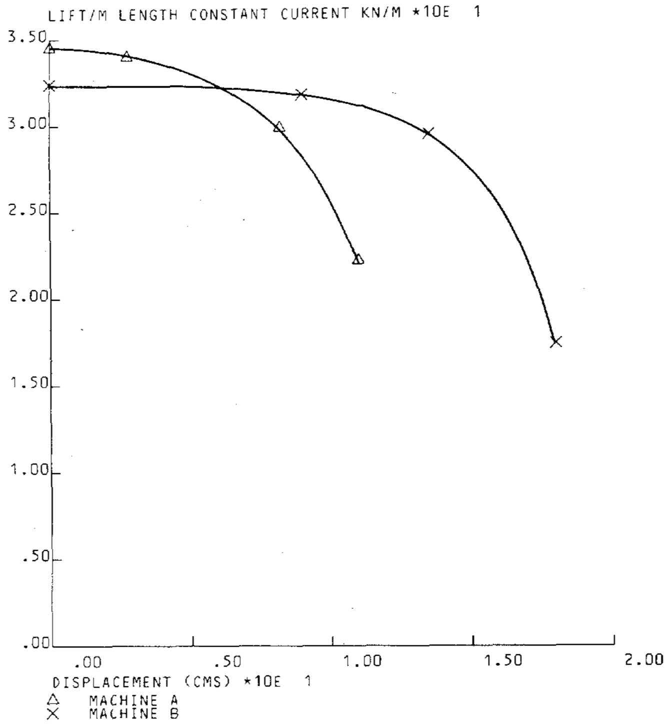

Fig 5 Lift/m length versus track displacement at constant current

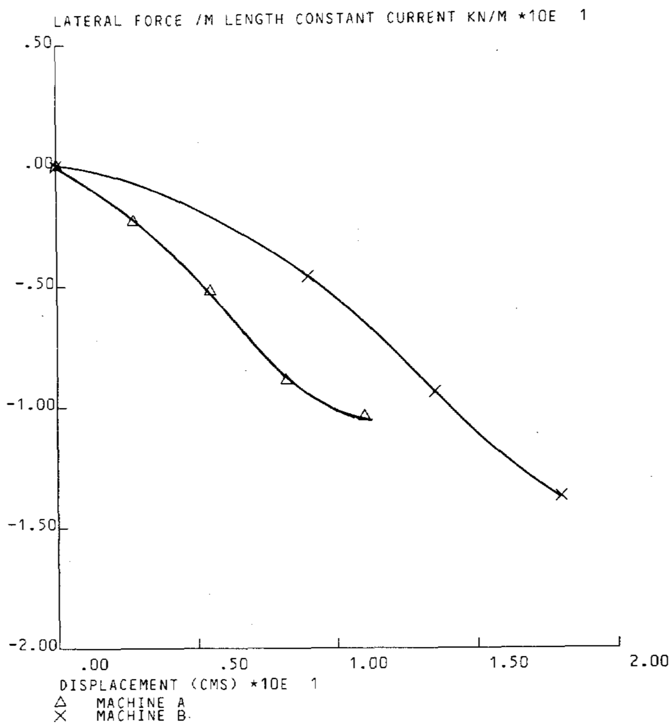

Fig 6 Lateral force/m length versus track displacement at constant current

Also shown is the maximum real power required by the devices. In order to keep the designs fairly general, this excludes stator I^2R losses. The weight of the respective stators is also shown, so that the amount of weight remaining from the 50 tonne total is 32.4 and 32.7 tonne for A and B respectively. A catamaran configuration is required to eliminate possible roll instability [2].

Although the results shown in Table 2 only apply at standstill, at least some likely benchmarks for the performance of large MAGLEV vehicles have been established. Drawbacks of the system which are obvious from Table 2 are the high values of kW per tonne lift. The weight of the machines is also a large fraction of the total vehicle weight. The high power requirement of the machine raises doubts about the feasibility of collecting megawatts of trackside power from a moving vehicle.

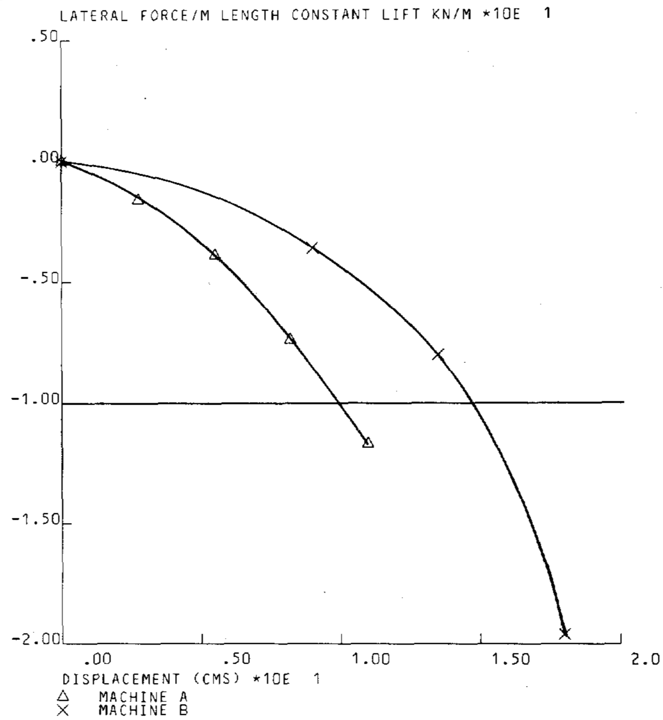

Fig 7 Lateral force/m length at a constant 2 cm clearance

CONCLUSIONS

An induction levitator has been tested with a variety of different secondaries. It has been shown that useful lateral stability, as well as levitation, can be provided by such devices. A low value of power factor is inherent in all those machines. This is not likely to be very important in low power applications, such as in small magnetic bearings or in instruments, but is an overwhelming disadvantage in applications such as MAGLEV.

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