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Conclusions

The aim of the research described in this dissertation has been to improve the performance of electromagnetic secondary suspension for vehicles through the use of improved control techniques.

The difficulties associated with the control of an electromagnetic vehicle suspension accrue from the nonlinear and unstable nature of the electromagnetic force characteristic. In addition, for systems which use electromagnets to provide both the primary and the secondary suspension functions, the direct coupling of the electromagnets to the vehicle chassis causes further complications by producing a multivariable control problem.

The proposed structured design approach requires the electromagnets to be controlled in such a way that they can be regarded as independent linear force actuators. The electromagnet force characteristic has therefore been analysed, and a detailed nonlinear model has been developed. Practical force control schemes employing only linear feedback techniques have been shown to be unsuitable for providing independent linear force actuation in an environment where a number of electromagnets are rigidly coupled. A new force control algorithm has therefore been developed which employs the detailed electromagnet model, in conjunction with electromagnet air gap and current feedback, to provide force actuation which is dominantly linear and independent.

Having obtained a suitably linear force actuation, the vehicle suspension is controlled by using linear transformations to translate between the electromagnet coordinate system and a vehicle coordinate system based on the heave, pitch, roll and torsion of the vehicle chassis. Each vehicle mode motion is then controlled by an independent suspension controller.

A sophisticated control algorithm has been developed to control the independent suspension modes. This consists of an absolute position controller, designed to achieve the required disturbance force rejection, which receives its position reference from a filtered version of the track position signal. All feedback signals are derived from measurements of the absolute acceleration and the air gap of each electromagnet. The structure of the new suspension control algorithm provides greater design flexibility than existing algorithms. This is because it permits the algorithm which defines the guideway following characteristic, to be designed largely independently of other suspension design considerations.

In order to obtain experimental responses in addition to simulated responses for the proposed vehicle suspension control scheme, an experimental suspension control system using digital signal processing has been developed. The signal processing hardware is based around the transputer family of microprocessors, and the control algorithms have been implemented using the occam parallel programming language. The simulated and experimental results presented in this dissertation have indicated the success of the proposed control method, to an extent where confidence is given in its potential for development to a full scale system.

The proposed electromagnet force control scheme has been shown to possess significant advantages compared with existing stabilisation techniques using flux derivative feedback due to its dominantly linear force actuation. However, it suffers a slight disadvantage due to an increased reliance on an accurate air gap measurement at small air gaps (see Chapter 3). If desired, this drawback could be overcome by developing a hybrid control approach combining flux derivative feedback, for stability, with the proposed scheme, for force linearity.

In addition, a number of areas which could benefit from further research have been identified. Firstly, an improvement in the modelling accuracy for the electromagnet core eddy-current time constant is desirable (see Chapter 2). Secondly, lateral force control through air gap modulation (see Chapter 4) may permit lateral damping for research vehicles using only suspension electromagnets. Thirdly, analysis of vehicle - guideway interaction and the development of suitable damping algorithms may be useful to permit the use of flexible guideways (see Chapter 1). Finally, and most importantly, guideway following algorithms need to be researched in order to minimise air gap deviations at the entrance and exit of gradients (see Chapters 1 and 4).

The results of this work suggest that with some additional research and development in the areas outlined above, electromagnetic suspension may in future provide an effective method for providing high ride quality, and low cost, for vehicle suspensions in urban transit applications. For wheel-on-rail transport applications, the wheel may then become a historical curiosity.