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THE MODELLING OF RAILWAY VEHICLES USING LUMPED PARAMETER TECHNIQUES

J.L. WEARING, DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF SHEFFIELD
C. PATTERSON, DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF SHEFFIELD
G.A. JEFFREY, BRITISH RAIL TECHNICAL CENTRE, DERBY

Abstract

In the design of railway vehicles it is important for the design engineer to be able to predict their dynamic response to ensure safety of operation and a satisfactory level of passenger comfort. He must be able, therefore, to adequately model the vehicle and the inputs if he is to obtain reliable results. In this paper the use of lumped parameter models for the analysis of bogied rail vehicles when the vertical dynamic input results from their passage over a dipped rail joint is discussed.

Introduction

The analysis of railway vehicles when subjected to vibration stimuli has been a problem which has attracted the interest of the engineer for many years. This interest has been motivated by a desire to reduce wear and damage to the vehicle and track and to improve ride qualities. With the modern trend towards higher running speeds and increased freight loads, it is more important than ever for the designer to be able to make sensible predictions regarding displacement and acceleration levels at points of major interest in the vehicle resulting from the vibrations as it progresses along the track. Good mathematical models of the vehicle and a thorough understanding of the factors producing the vibrations are required, therefore, if the analysis is to yield satisfactory results.

Vibration stimuli of the vehicle can result from various sources during travel. They can arise for example from out-of-balance forces in the wheels a flat spot on the wheel, flexing of the rail between sleepers and negotating points and joints between rails. One of the most severe inputs to the vehicle results from the joints between rails.

It is in only recent years, with the advent of modern computing facilities that mathematical models, which adequately account for all aspects of the problem, have been able to be formulated and solved. The vibration analysis of bogied rail vehicles when the input is in the form of a dipped rail joint is discussed in this paper. The vehicle is modelled as lumped parameter system and the resulting equations are solved using an analogue computer style approach on a digital computer.

Vehicle Analysis and Results

A bogied rail vehicle consists of a body supported on the bogies by the secondary springs and dampers. The bogies and wheel sets are connected by the primary springs and dampers. The vehicles which are considered in this paper have two bogies and each bogie has two sets of wheels as shown in figure 1.

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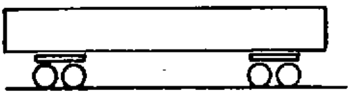

Fig. 1. Bogied Rail Vehicle

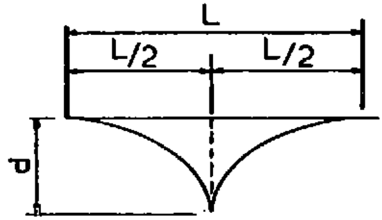

Fig. 2. Dipped Rail Joint

In the formulation of the mathematical model it is necessary to ensure that all relevant parameters are included. The basic approach which has been adopted in this work is to use lumped parameter techniques to model the vehicle. A vehicle is considered in isolation, assuming that adjacent vehicles have no effect, and in the analysis it is assumed that all springs and dampers are linear. The input, which is considered, arises from travel over a dipped joint having the profile shown in figure 2. Although the joints between rails on opposite sides of the track do not have identical profiles, it has been assumed in the analysis that they are identical.

A comprehensive study has been carried out by one of the authors (1) on the use of lumped parameter models for the analysis of bogied rail vehicles when subjected to vertical inputs of the type discussed in this paper. The number of degrees of freedom in the model varied from three to eight depending on how much of the vehicle was included. In the three degree of freedom model a bogie was considered in isolation, the degrees of freedom being the vertical and pitching motion of the bogie and the vertical motion of the secondary suspension system. Vertical and pitching motions of the body and of each bogie and vertical motion of each suspension system were the degrees of freedom considered in the eight degree of freedom model. In the four, five and six degree of freedom models, a symmetrical half of the vehicle was considered. For example in the four degree of freedom model vertical and pitching motion of the bogie vertical motion of the secondary suspension system and vertical motion of half of the body were the freedoms which were considered. Each model was analysed for the vehicle negotiating a dipped joint of the form shown in figure 2 when travelling at a velocity of 43.1 ms^{-1}. The shape of each side of the joint was assumed to be parrabolic and its length and depth were 5.4 m and 15 mm respectively.

A thorough computer study of the models was undertaken and the equations of motion were formulated by developing analogue models on the visual display unit of the digital computer at British Rail Technical Centre, Derby. On satisfactory formulation they were then solved using the Runge-Kutta technique.

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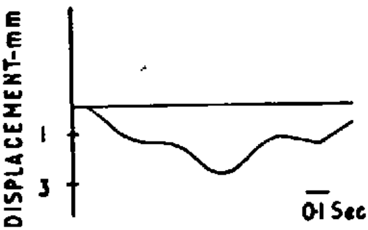
The main results,which were obtained from the calculations, were displacement acceleration and force time histories of the vehicle as it traverses the dipped joint. A knowledge of these results are important to the engineer it the design parameters of the vehicle are to be satisfied. For example, in passenger vehicles acceleration levels must be kept to a minimum to satisfy comfort requirements. In freight trains, if excessive acceleration and displacement levels are transmitted to the body of the vehicle damage of the cargo can ensue. A knowledge of the magnitudes of the forces which are transmitted through the suspension units to the bogies are of vital importance to the designer for the determination of stress levels. Examples of the large number of results which were obtained in the course of the work, are shown in figures 3 and 4. Figure 3 shows the variation of vertical displacement of the body and figure 4 indicates the secondary suspension forces on the bogie frame. Both graphs were obtsined from the eight degree of freedom model.



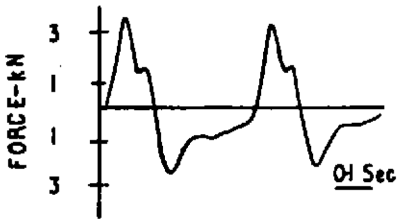


Fig. 3. Vertical Displacement of Body Fig. 4. Secondary Suspension Forces on Bogie

On examination of the many records, which were obtained, it was found that, where the same degree of freedom appeared in different models, the level of agreement between results was good. It was observed, for example, that the values obtained for the maximum values of the vertical displacements of the bogie frame centre showed good agreement from all models. The value obtained from three, four and eight degree of freedom models were 6.9 mm and 7.1 mm and 7.3 mm respectively. Values obtained for bogie frame maximum pitching displacement also differ very little between models. The three, six and eight degree of freedom models produced values of 0.0065 rad., 0.007 rad., and 0.0064 rad.,respectively. Other results showed similar agreement. For example the values obtained for the secondary suspension forces on the bogie centre yielded numerically similar values for all the models which were analysed. The curve shapes, which were produced showed close similarity with the maximum value being around 3.75 kN. Values of acceleration levels show similar close agreement. When the calculated results were compared with experimental values which were obtained from extensive field trials by British Rail Technical Centre, Derby, the agreement was found to be good.

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Discussion and Conclusions

Dynamic forces in railway vehicles result from its passage over the track and arise from various sources such as out-of-balance forces in the wheels and the flexing of the rails between the sleepers. The work on which this paper is based was concerned with the vibrations of the vehicle due to vertical inputs. One of the most severe forms of input to produce vertical vibrations of the vehicle results from the dips occurring in rails at the joints. The techniques which are discussed, therefore, in this paper for the determination of the responses of the vehicle deal with inputs from such joints.

The forces which are transmitted from the track induce forces, displacements and accelerations in the vehicle. The designer must be able to predict these parameters with confidence if he is to ensure that stresses in the vehicle, and levels of passenger comfort, are kept within acceptable limits. The suspension units govern these parameters and their values must be chosen at the design stage. This means that the engineer must have at his disposal suitable mathematical models of the vehicle and the inputs and facilities to solve these equations. In this paper lumped parameter models were used to model the vehicle and the dipped joint was assumed to have the form indicated in figure 2. In the analysis complete linearity of the suspension units was assumed and the input to the vehicle on each side of the track was assumed to be identical.

The results which were obtained from the analysis for the various responses of displacement acceleration and force compared favourably with experimental results. Results from the different models tested showed good agreement with each other. The techniques which are discussed in this paper, the assumptions, which are made and the method of solving the equations, appear, therefore, to be satisfactory and can be used for the determination of the various responses.

Reference

(1) G.A. JEFFREY. Aspects of Vertical Dynamic Modelling of Bogied Rail Vehicles, M.Eng. thesis, Department of Mechanical Engineering, University of Sheffield, 1979.