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A STUDY OF PASSENGER RIDE COMFORT IN RAIL VEHICLES

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

Abstract

The prediction of the dynamic response of railway vehicles is of considerable importance to the design engineer in enabling him to determine resulting stress levels and levels of passenger comfort. Vibrations are stimulated from various sources and in this paper the vertical response of bogied rail vehicles resulting from dipped rail joints is discussed. Particular emphasis is placed on the effect of these inputs on passenger comfort.

Introduction

For many years the vibration of railway vehicles has stimulated interest which is motivated by a desire to improve ride qualities and reduce wear and damage to the vehicles.

The current trend of higher running speeds and increased freight train loads makes is increasingly more important for the designer to be able to predict the displacement and acceleration levels resulting from vibrations of the vehicle. This enables him to ensure for example that stresses and passenger comfort are kept within acceptable limits. A thorough understanding of the causes affecting the vibrations and an ability to accurately model the vehicle is required, therefore, if he is to formulate a suitable mathematical model for the analysis of the vehicles.

The vibration stimuli for the vehicle results from its progress over the track and the mathematical investigation of the complete problem to include all types of vibration is extremely complex. It is, however, possible to analyse independently certain aspects of the problem. One important area of vibration is that resulting from vertical inputs which can result from out-of-balance forces in a wheel set, or flat spot on a wheel, a discontinuity in the track at a rail joint, flexing of the rail between sleepers or negotiating points or crossings.

In this paper the analysis of vibration of bogied vehicles due to discontinuities at rail joints is discussed. The vehicle is modelled as a lumped parameter system. The equations are solved using an analogue computer style approach on a digital computer and results of the analysis are presented.

Mathematical Modelling of the Vehicle

The analysis considers the vertical dynamics of four axled vehicles comprising of a body and two bogies, each bogie having two axles, as shown in figure 1. Each axle unit is connected to a bogie by a primary suspension and each bogie is connected to the body by means of a secondary suspension.

A STUDY OF PASSENGER RIDE COMFORT IN RAIL VEHICLES

Lumped parameters are used to derive the equations of motion and the mathematical models. Consider a rail vehicle in isolation, assuming no influence from adjacent vehicles. The number of degrees of freedom in the model can vary between three and eight depending on the information required.

Vertical oscillations result from various stimuli, one of the least favourable arising from the rail displacement at joints, even in modern welded track. Vibrations ensue when the vechile runs over the joint which has a profile as indicated in figure 2.

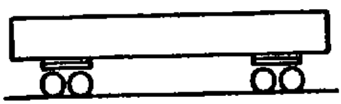

Fig. 1

Bogied Rail Vehicle

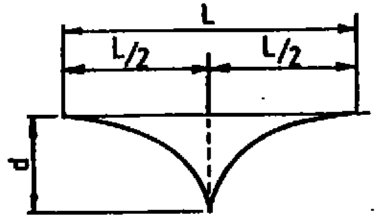

Fig. 2

Dipped Rail Joint

Passenger Comfort

Passenger comfort by its definition must contain a subjective element. The designer must have, however, a criteria for assessing the level of comfort in the vehicle.

It is well known that accelerations in the frequency range 0-30 Hz are among the worst causes of passenger discomfort (1) with particular problems occurring around the 4-6 Hz region where body organ resonances are excited. As a means of minimizing the effects of acceleration at these low frequencies, the rail vehicle designer uses a ride factor criterion which is based on acceleration and frequency. The results on which the criterion is based arises mainly from the work of Mauzin of the S.N.C.F. and Sparling (2) of the Deutches Bundesbahn. Mauzin obtained his results from a large series of tests based on passengers' subjective assessment of comfort on railway vehicles of diverse types. Sparling's results were obtained from laboratory tests by subjecting people to sinusoidal tests of varying frequency and amplitude and recording their assessment of discomfort. Both studies showed remarkably good agreement and ride index curves of frequency against acceleration of the type shown in figure 3 were obtained. A comfort factor between 1 and 5 is assigned to each curve all of which exhibit the vee shaped characteristic indicated, with a minimum around 5 Hz.

Results

In the analysis for the response to vertical inputs, the equations were assumed to be completely linear as any non-linearities in the suspension systems are negligible.

In a comprehensive study by one of the authors (3) models having four, five, six and eight degrees of freedom were analysed. In the eight degree of freedom model vertical and pitching motions of the body, vertical and pitching motions of each bogie and vertical motion of each secondary suspension were the freedoms considered. A symmetrical half of the vehicle was analysed in the four degree of freedom model to include vertical and pitching motions of one bogie, vertical motion of half of the body and vertical motion of one secondary suspension. The models with five and six degrees of freedom also considered half of the vehicle, the former modelling the bogie as a three mass system. The latter model included the same motions as the four degree of freedom model but had, as additional freedoms, the vertical motions of each wheel set (including an adjacent portion of the track) connected to earth by a spring and damper.

In each analysis vertical oscillations were stimulated by the vehicle travelling over a dipped joint (figure 2) at 43.1 m s^{-1}. The length and depth of the dip were 5.4m and 15 mm respectively and the shape of each side of the dip was assumed to be parabolic.

The results for the vertical acceleration of the body compare favourably for each model tested, the exception being the eight degree of freedom model. In the case of the models with close similarity of results time histories and maximum values of acceleration show good agreement. All acceleration-time graphs of the body acceleration, as the vehicle traverses a dipped joint, take the form of that shown in figure 4.

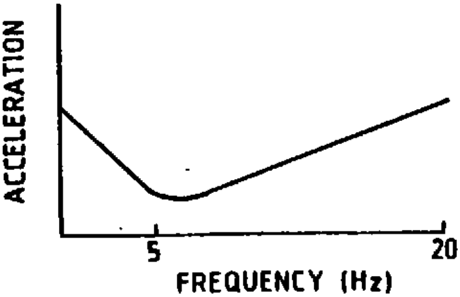

Fig.3
Ride Index Curve

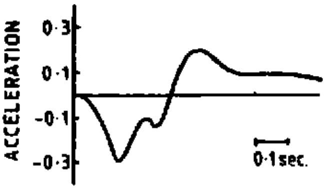

Fig. 4
Vehicle Body Acceleration

A STUDY OF PASSENGER RIDE COMFORT IN RAIL VEHICLES

Discussion of Results and Conclusions

The velocity of the vehicle in the analysis was 43.1 ms^{-1} and the length of a rail section is 18m making a dominant excitation frequency around 2.5Hz. The peak values of acceleration which were obtained in the analysis showed good agreement and varied between 0.295 ms^{-2} and 0.315 ms^{-2} for various models tested.

A joint depth of 15 mm was used in the analysis and is on average larger than that normally experienced by high speed trains on fast track. This means that, if the joint was modelled with a smaller depth, it would predict lower accelerations.

All acceleration - frequency ride index curves exhibit the vee shaped characteristic shown in figure 3 and at any particular frequency the ride index increases with acceleration. Hence families of curves can be produced, each curve relating to a particular index and if the vehicle body acceleration is known the ride index at any particular frequency can be obtained from the appropriate curve.

Ride index factors can vary from around 1.0 to 5.0 with 1.0 being classed as very good and 5.0 as intolerable. A maximum value of about 2.0 is generally regarded as a satisfactory design criterion which limits the body acceleration to around 0.3g to 0.35g. That means that the predicted acceleration from a dipped joint having a depth of 15 mm would give a satisfactory ride index factor for the vehicle. As a smaller joint, giving lower accelerations, is more normal, predicted ride index factors would be lower.if such a joint was used in the analysis.

References

(1) C.M. HARRIS and C.E. CREDE (editors). Shock and Vibration Handbook, Mc Graw-Hill, New York, 1961.

(2) W. HELBERG and E. SPERLING. Verfahren zur, Beurteilung der Laufeigenschaften von Eisenbahnwagen. (Method of Estimating the Qualities of Ride of Railway Coaches), Organ fur d. Fortschr. a Eisenbahnwesens, 1941.

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