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MODELLING THE BEHAVIOUR OF FREIGHT VEHICLES

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INTRODUCTION

An understanding of the dynamic behaviour of a railway vehicle is not only essential for vehicle designers but can give those concerned with railway vehicle operation and infrastructure maintenance an insight into various potential problems and the methods of ameliorating these.

Using modern computer modelling techniques it is possible to carry out realistic simulation of the dynamic behaviour of railway vehicles. The theoretical basis of the mathematical modelling used is now mature and reliable and programs originally written by research institutes have been developed into powerful, validated and user friendly packages. Using specialised programs such as Adams-Rail, Medyna, Nucars, Simpack or Vampire it is possible to analyse the effects of various track configurations on the running of vehicles or, conversely, to evaluate the effects of vehicles with different suspension design or levels of wear etc on the track.

Freight vehicles have suspensions which are particularly difficult to analyse because of the presence of friction and clearance which cause the equations describing the vehicle dynamics to be highly non-linear.

MODELLING

The first stage in setting up a computer model is to prepare a set of mathematical equations which represent the vehicle. These are called the equations of motion and are usually formed as a set of matrices. The equations of motion can be prepared automatically by the computer package, a user interface requiring the vehicle parameters to be described in graphical form or by entering a set of co-ordinates describing all the important aspects of the suspension. The amount of detail used to prepare the model will vary according to the type of suspension and the required outcome of the modelling exercise.

The vehicle is represented by a network of bodies connected to each other by flexible elements. This is called a multibody system and the complexity of the system can be varied to suit the vehicle and the results required. The bodies are usually rigid but can be flexible with a given value of stiffness. Masses and moments of inertia need to be specified. Points on the bodies, or nodes, are defined as connection locations and dimensions are specified for these. Springs, dampers, links, joints, friction surfaces or wheel-rail contact elements can be selected from a library and connected between any of the nodes. Points in the multibody system are defined as inputs and exciting forces can act at these.

INPUTS

Inputs to the model are usually made at each wheelset. These must describe the position and velocity of the rail contact point at each wheel. Typical inputs are cross level, gauge and lateral alignment for the track. These can be idealised discrete events such as a dipped joint or can be measured values from a real section of track. Additional forces may be specified where wind loading or cant deficiency is significant or when there are powered actuators present.

SOLUTION METHODS

The method of solving the equations of motion will depend on the data available and the required output.

1. EIGENVALUE ANALYSIS

At an early stage of the modelling it is often useful to carry out an eigenvalue analysis. The eigenvalues are calculated from the equations of motion and give an indication of the natural frequencies of the various modes of oscillation possible for the vehicle bodies. This can be used to identify possible problems for example with a particular mode being excited by a cyclic element in the track. An eigenvalue analysis can also be used to indicates the critical speed at which the instability, known as hunting, is likely to occur. An example is shown in figure 1.

2. STOCHASTIC ANALYSIS

A complex transfer function can be calculated from the equations of motion and used to find the frequency spectrum of the response of any part of the vehicle to a known track spectral density input.

This is an ideal method to use when there is a problem with vehicle ride and can also help with vehicle acceptance procedures where vibration levels must be shown to be less than a limit specified in the frequency spectrum.

Figure 1. Two eigenvalues for a vehicle with 3-piece bogies

3. STEP BY STEP INTEGRATION METHOD

Freight vehicles usually contain non-linearities in their suspension such as clearance, bump stops, multi-stage dampers and friction in sliding elements and at the wheel-rail contact point due to creep and flange contact. Because of the presence of these non-linearities the equations of motion cannot be solved analytically. It is, however, possible to use a numerical method to integrate the equations at time intervals over the simulation period, the results at each point being used to predict the behaviour of the system at the next time step. Many methods are available to perform this time stepping integration, for example the Runge-Kutta techniques are widely used and usually give good results.

At each time step the equations of motion are set up and all the suspension non-linearities are evaluated. The creepages and creep forces between the wheels and rails are found and the resulting accelerations at each body for each degree of freedom are calculated.

EXAMPLES

Two examples are now given to illustrate the modelling methods and the types of simulation output that may be obtained.

THE '3-PIECE' BOGIE

The 3-piece bogie, although not common in Western Europe, is widely used in North America, Australia, Africa and Russia. The wheelsets support two side frames which in turn support a bolster. Connection from the bolster to the car body is via a central pivot and side bearers with sliding surfaces. Vertical and lateral suspension between the side frames and the bolster is provided by a spring unit which consists typically of 7 sets of concentric springs. The resulting unsprung mass is higher than for a vehicle with a primary suspension (stiffness between the wheelset and bogie).

Damping is achieved by spring loaded snubbing wedges acting between the ends of the bolster and each side frame. These wedges are arranged such that a proportion of the car body weight is passed through the wedges causing the normal force at the friction surfaces, and therefore the damping, to vary with vehicle load.

The main difficulties for the modeller are the clearances which are present between the axleboxes and the side frames and between the side frames and the bolsters and also the friction surfaces which see normal forces which vary with the vehicle motion.

The computer package MEDYNA was used for this work and has friction elements included for sliding in one plane or in two and allows consideration of a dynamically varying normal force. The normal force is taken from the force in the spring underneath the snubbing wedge and applied to the element. A vector of the relative motion of the two surfaces is calculated and friction force calculated using the chosen coefficient of friction and checking at each step for saturation.

A typical bogie is shown in figure 2 and a sample plot of the friction force at the wedge is shown in figure 3.

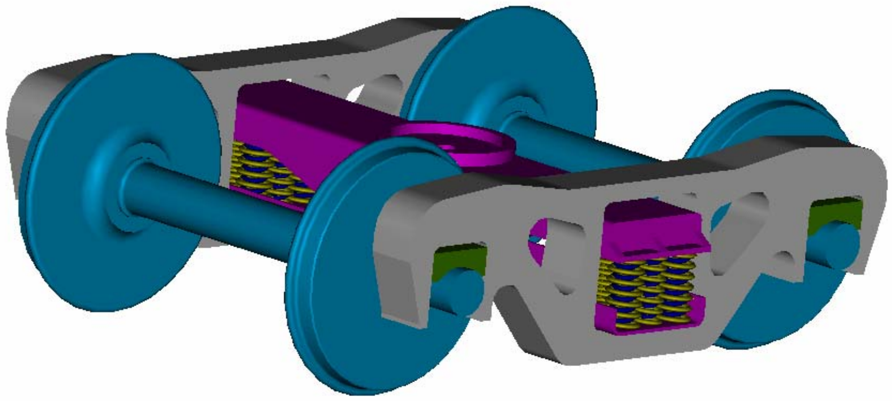

Figure 2. A typical 3-piece freight bogie

Figure 3. Simulated friction force at the wedge in a 3-piece bogie

LEAF SPRING SUSPENSION

Leaf spring type suspensions were used on the first railway vehicles and are still widely used due to their low cost. Multi-leaf springs also provide part or all of the required damping as friction between the leaves dissipates energy. MEDYNA, as with other packages, allows this to be modelled with the user being required to specify the number of leaves and stiffness of each and also to estimate the coefficient of friction (often the most difficult aspect as the friction is affected by the environment).

A typical leaf spring suspension is shown in figure 4.

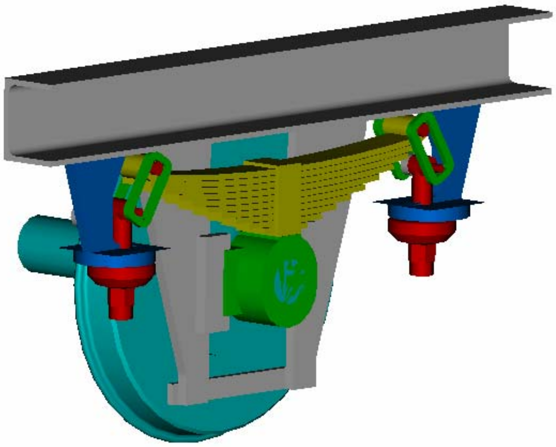

Figure 4. A typical leaf spring suspension

RESULTS

Models of a 4 wheel wagon with leaf spring suspension and a three-piece bogie vehicle have been set up using MEDYNA and simulations carried out on a variety of track cases with idealised defects such as cyclic top and dipped rail joints. These results are currently being used to predict levels of track damage in response to changes in vehicle configuration and track condition.

Figure 5. shows simulated vertical track force with changing friction coefficient at the wedge for the 3-piece bogie and figure 6. shows the peak accelerations at the body for both vehicles.

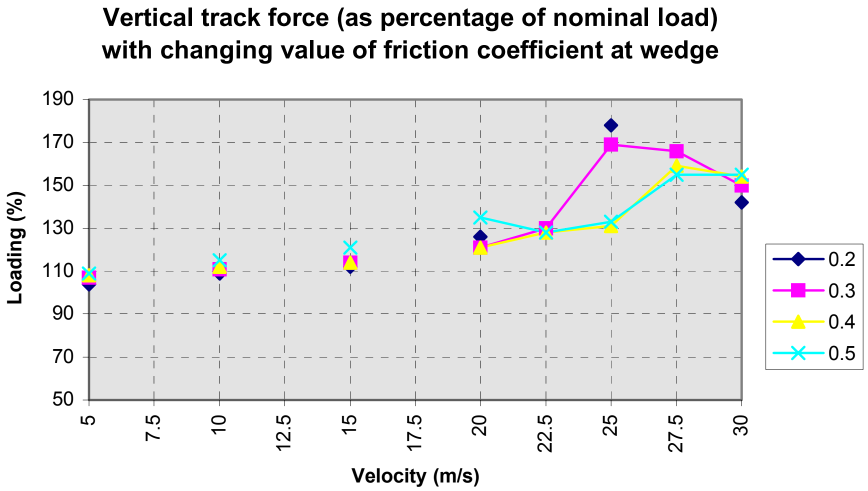

Figure 5. Simulation of track force at various speeds in response to cyclic top input

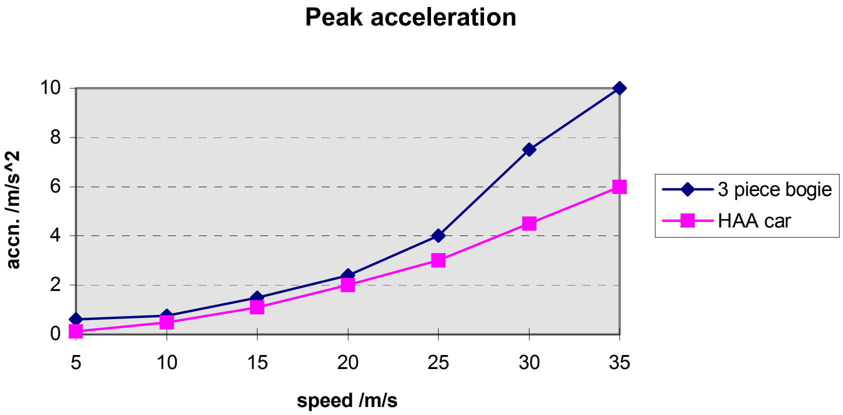

Figure 6. Simulation of body accelerations in response to cyclic top input

CONCLUSIONS

The results shown above represent examples of the output that can be generated by modern simulation packages. Once a model has been set up it is relatively easy to vary parameters of interest and analyse the effect on the vehicle behaviour and the interaction with track of different types.

This provides a real alternative to on track testing with the opportunity to quickly and easily investigate a range of track or vehicle parameters. This can provide information to help make decisions about maintenance periodicity for track and vehicles and the financial implications of track and vehicle condition.

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REFERENCES

Eickhoff B.M., Evans, J.R. and Minnis, A.J.
'A review of modelling methods for railway vehicle suspension components'
Vehicle System Dynamics, 24(1995), pp. 469-496
Swets & Zeitlinger 1995

Kik W. Iwnicki S.D. Boronenko Y.P. Pobedimov V.K.
'Analysing the dynamic behaviour of Russian railway vehicles using the simulation tool MEDYNA'
9th International Conference on Problems in Mechanics of Railway Transport
Dnepropetrovsk May 1996

The Rail Technology Unit

The **Rail Technology Unit** based at **Manchester Metropolitan University** carries out research and consultancy into the dynamic behaviour of railway vehicles and their interaction with the track.

We use state of the art simulation tools to model the interaction of conventional and novel vehicles with the track and to predict track damage, passenger comfort and derailment. Our simulation models are backed up by validation tests on vehicles and supported by tests on individual components in our test laboratory. We are developing methods to investigate the detailed interaction between the wheel and rail.

January, 2004
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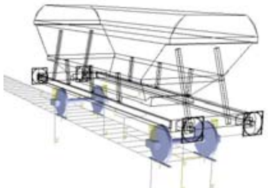

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