TECHNOLOGY DIGEST

Timely Technology Transfer

Improved Vehicle Dynamics Model for Tri-Level Auto-Rack Railcars

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TD 97-038

Summary

Research engineers have constructed a high-fidelity vehicle-dynamics computer model using NUCARS to assist in designing and estimating performance of future tri-level auto-rack suspensions. Experimental data obtained during tests on the Vibration Test Unit (VTU) at the Association of American Railroads' (AAR) Transportation Technology Center near Pueblo, Colorado, was used to calculate the tri-level car-body parameters, such as mass moments of inertia and center-of-gravity location. A simple automobile model was constructed using dynamic parameters obtained from a literature survey. The tri-level and automobile models were synthesized to arrive at a loaded tri-level dynamic model.

This is the first dynamic model validated with track test data of a tri-level auto rack. The ability of the model to predict the dynamic behavior of the tri-level was confirmed by comparing simulation results to data obtained during both track and VTU tests at TTC. The accuracy of the model is a result of the extensive characterization tests conducted on the VTU.

This project is a continuation of a program which began in 1995 to identify new suspensions for auto-rack cars (Reference TD 96-021 and TD 96-022). The program is the result of automobile manufacturers and railroad representatives working together to define new requirements for auto-rack ride quality. The requirements are summarized in a Recommended Practice RP-803-96 titled: Ride Quality Performance Requirements for Motor Vehicle Shipments. The work described here was funded by the Quality and Maintenance of Equipment joint working group and is supplemental to the AAR Advanced Freight Car Truck Design Program, the focus of which is to promote the development of innovative suspensions for multi-level auto-rack cars.

Suggested Distribution:

- ❑ Equipment/Rolling Stock
- ❑ Research & Development
- ❑ Intermodal
- ❑ Car Department

Association of American Railroads
Railway Technology Department

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INTRODUCTION AND CONCLUSIONS

The Association of American Railroads has constructed and validated a dynamic computer model based on tests conducted on a tri-level auto rack using the Vibration Test Unit (VTU) at the Transportation Technology Center near Pueblo, Colorado. The model is to be used in development of new trucks for auto-rack service, and evaluation of their performance. The performance of the new trucks is quantified by measuring accelerations at the railcar deck in controlled on-site tests and during over-the-road tests on railroad property.

Two VTU tests were conducted. The first involved testing an unloaded tri-level auto rack. The second involved testing a loaded tri-level auto rack, shown in Exhibit 1. Both involved exciting the rigid-body and first-flexible-body modes of vibration of the tri-level using wheel-displacement inputs to determine the resonant frequencies. The tests were performed with ASF machine center trucks supplied by TTX. This truck serves as the baseline for performance evaluation of improved suspensions. As a result of this work, researchers:

- Experimentally determined the tri-level car body dynamic parameters (i.e. mass moments of inertia and center-of-gravity height).
- Constructed an accurate empty tri-level dynamic model and verified the model accuracy by comparing unloaded test data to computer simulation results.
- Observed that automobile suspensions have a significant impact on railcar dynamic performance.
- Constructed an accurate loaded tri-level dynamic model to include a simple automobile model and verified the model accuracy by comparing loaded test data to computer simulation results.

METHODOLOGY

In developing an accurate tri-level dynamic model, researchers:

- Conducted the unloaded VTU test to determine rigid-body and first-flexible-body natural frequencies of an empty tri-level auto rack.

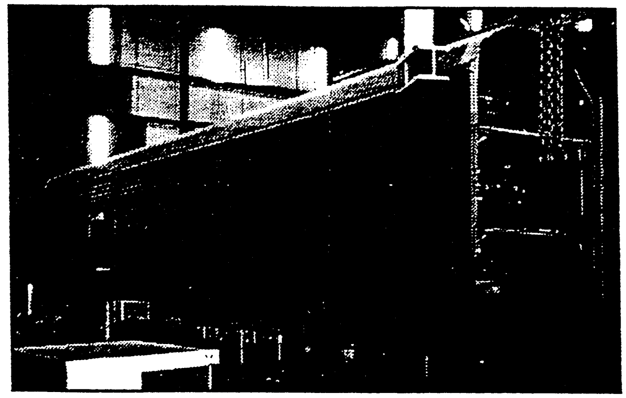

Exhibit 1. Loaded Tri-level on the VTU

- Calculated roll, pitch, and yaw inertias and the center-of-gravity height of the tri-level car body using the measured rigid-body natural frequencies.
- Constructed the dynamic model of the tri-level auto rack using the inertias, center-of-gravity height, and first-flexible-body natural frequencies.
- Simulated the unloaded VTU test using NUCARS, and compared results to test data.
- Conducted loaded VTU tests to investigate effect of automobile live load.
- Estimated automobile characteristics from literature search and VTU test data.
- Included dynamic models of the 15 automobiles in the tri-level auto-rack model.
- Simulated loaded VTU test using NUCARS, and compared results to test data.

VTU TESTING APPROACH

The unloaded and loaded VTU tests were executed using similar procedures. Both involved exciting the rigid-body and first-flexible modes, as illustrated in Exhibit 2, of the tri-level. The rigid-body modes were excited using swept sine (0.5 Hz/min) constant amplitude wheel displacements. The flexible-body modes were excited, after inserting rigid steel pipes in the spring nest to block the railcar suspension, using swept sine constant amplitude wheel accelerations. For each mode, strategically located accelerometers collected time history data. Fast Fourier Transforms

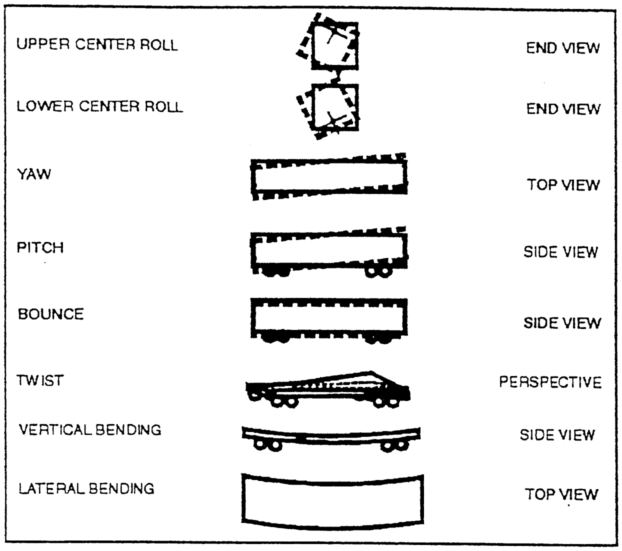

Exhibit 2. Railcar Modes of Vibration

(FFTs) were conducted on the time history data to identify the resonant frequencies.

UNLOADED VTU TEST

The objective of the unloaded VTU test was to measure the rigid-body and first-flexible-body resonant frequencies of an empty tri-level auto rack. The results are listed in Exhibit 3. Using the measured resonant frequencies, the dynamic parameters (roll, pitch, and yaw inertia and center-of-gravity height) and the truck-suspension characteristics (vertical and shear stiffness) were calculated, as listed in Exhibit 4.

Mode	Resonant Frequency
Bounce	2.56 Hz
Pitch	2.87 Hz
Yaw	1.91 Hz
Upper Center Roll	2.71 Hz
Lower Center Roll	0.84 Hz
Twist	5.90 Hz
Vertical Bending	6.11 Hz
Lateral Bending	14.55 Hz

Exhibit 3. Unloaded Tri-level Resonant Frequencies

LOADED VTU TEST

The tri-level was loaded with 15 Toyota Camrys. The resonant frequencies of the loaded car are listed in Exhibit 5. In the past, automobiles were shipped chained down to the auto-rack deck, thus eliminating the automobile suspension. Because the automobiles are now shipped sitting freely on their own suspensions, with the wheels chocked, they become a live load. This results in at least two system resonant frequencies for each mode. The frequency recorded in Exhibit 5 is the frequency in which the tri-level was the most active.

Parameter	Value
Roll Inertia	1,393,000 lb in s^2
Pitch Inertia	31,540,000 lb in s^2
Yaw Inertia	31,510,000 lb in s^2
Center of Gravity Height	93 in
Truck Vertical Stiffness	34,750 lb/in
Truck Lateral Stiffness	15,230 lb/in

Exhibit 4. Tri-level Dynamic Parameters

Mode	Resonant Frequency
Bounce	2.93 Hz
Pitch	3.12 Hz
Yaw	1.54 Hz
Upper Center Roll	3.00 Hz
Lower Center Roll	0.73 Hz
Twist	N/A
Vertical Bending	N/A
Lateral Bending	N/A

Exhibit 5. Loaded Tri-level Resonant Frequencies

TRI-LEVEL DYNAMIC MODEL

Using the parameters in Exhibit 4, a dynamic model of the tri-level was constructed. The automobiles were modeled using the mass, mass moments of inertias, and center-of-gravity location given in "Vehicle Inertial Parameters-Measured Values and Approximations," SAE Paper 881767, by Garrott, Monk, and Chrstos. The stiffness and damping of the automobile suspension was estimated from VTU test data and literature.

The VTU tests were simulated using NUCARS and compared to test data. Exhibit 6 lists the frequencies calculated in the unloaded simulation. The agreement between the simulation results

Mode	Resonant Frequency
Bounce	2.62 Hz
Pitch	2.83 Hz
Yaw	1.91 Hz
Upper Center Roll	2.71 Hz
Lower Center Roll	0.84 Hz
Twist	5.89 Hz
Vertical Bending	6.15 Hz
Lateral Bending	14.55 Hz

Exhibit 6. NUCARS Unloaded Tri-level Resonant Frequencies

(Exhibit 6) and test data (Exhibit 7) indicate an accurate empty car model. Exhibit 7 lists the frequencies at which the tri-level car-body motion was dominant during the loaded simulation, and compares favorably with the loaded-car test data (Exhibit 5).

However, since the automobiles are a live load, simply looking at a single resonant frequency is not adequate. Therefore, FFTs of dynamic model accelerations are compared to FFTs of accelerations measured during the test. As an example, the comparison for the bounce test is illustrated in Exhibit 8 and Exhibit 9, which demonstrate the FFTs of accelerometer data calculated in NUCARS

Mode	Resonant Frequency
Bounce	2.93 Hz
Pitch	3.12 Hz
Yaw	1.47 Hz
Upper Center Roll	2.35 Hz
Lower Center Roll	0.59 Hz
Twist	N/A
Vertical Bending	N/A
Lateral Bending	N/A

Exhibit 7. NUCARS Loaded Tri-level Resonant Frequencies

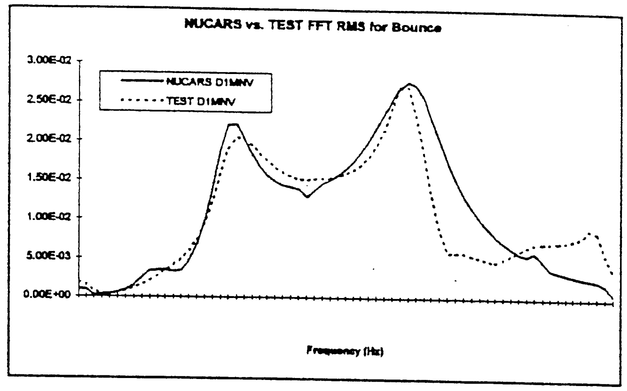

Exhibit 8. NUCARS vs. VTU Test FFT for Tri-level Deck Accelerometer in Bounce Mode

compared to the corresponding FFTs of accelerometer test data. The accelerometer in Exhibit 8 was located on the first deck on the left side (A-End as front) with a longitudinal position approximately in the middle. The accelerometer in Exhibit 9 was located on the engine of the automobile on deck 1 at the A-End. The exhibits indicate good agreement between the loaded tri-level dynamic model simulation and test data.

Note: Contact Scott Burnett at (719) 585-1807 with questions or comments about this document.
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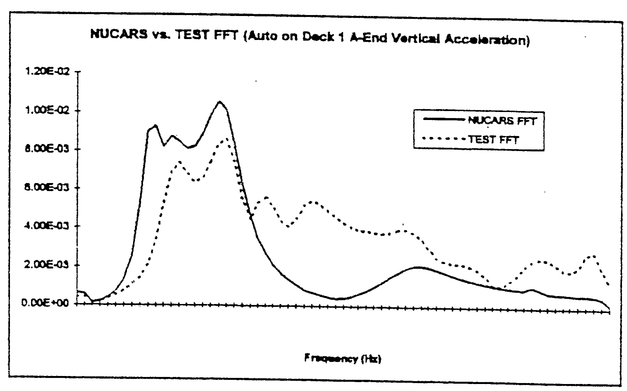

Exhibit 9. NUCARS vs. VTU Test FFT for Automobile in Bounce Mode

A MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER PROCESSING, 50 F STREET, NW, 5TH FLOOR, COG, WASHINGTON D.C., 20001