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# Instrumented Wheelset System Results Verified the High Speed Safety Standards

## SUMMARY

To improve the safety of high-speed passenger coaches, the Federal Railroad Administration sponsored research to develop an instrumented wheelset system that collects wheel/rail forces and acceleration data on a high-speed passenger coach and then compares vehicle performance with newly adapted vehicle track interaction (VTI) safety limits. Data was collected over a 450 mile round-trip route on the Northeast Corridor (NEC) between Washington, DC, and New York City. This data was then compared to the VTI limits in the High-Speed Safety Standards to verify that the passenger coach ran under safe conditions.

The completed tests demonstrated that the instrumented wheelset system accurately measures wheel forces and accelerations. A VTI exception report showed that there were no exceptions to the VTI safety limits specified in the standards for high-speed track safety on NEC throughout these tasks.

Table 1 shows a summary of a VTI exception report from Wilmington to Baltimore when VTI limit is lowered to 60 percent of safety limit. This report lists the type of exception, the percent of the safety limit, peak value, speed, and location. As an example, the third row shows a net-axle lateral force on axle 2 that was -12,985 pounds. This corresponds to 86.6 percent from the limit of ±15,000 pounds. This occurrence happened at 7,695 feet South of milepost 36. This exception was also the highest occurrence for the entire round trip from Washington, DC to New York City.

***Table 1. Exception Report at 60 Percent of the Vehicle-Track Interaction Limits on the Northeast Corridor from Wilmington to Baltimore, June 1999.***

| Type of Exception | Percent of Limit | Value | Speed (mph) | Milepost | Feet |
|---|---|---|---|---|---|
| L/V, wheel 2A | 62.3 | 0.633 | 117.9 | 36 | 7,695 |
| T-L/V, right side | 69.8 | 0.419 | 117.8 | 36 | 7,695 |
| **NAL, axle 2** | **86.6** | **-12,985 pounds** | **117.9** | **36** | **7,695** |
| CB, lateral | 61.2 | 0.306 g | 118.0 | 36 | 7,652 |
| L/V, wheel 1B | 65.9 | 0.669 | 115.0 | 40 | 3,224 |
| NAL, axle 2 | 63.0 | -9,456 pounds | 114.9 | 40 | 3,232 |
| CB, lateral | 60.4 | 0.302 | 115.0 | 40 | 3,198 |
| NAL, axle 2 | 68.0 | -10,194 pounds | 0117.8 | 74 | 6,973 |

## BACKGROUND

The purpose of the instrumented wheelset system is to gather simultaneous measurements of wheel/rail forces, wheel/rail contact positions, and vehicle accelerations in response to measured track geometry variations under high speed conditions. Wheel/rail forces and wheel/rail contact positions are measured with strain gauge bridges installed on a typical railroad wheel. The four wheels of a single truck, axles and truck assembly, are instrumented to give a more complete picture of the dynamics of the vehicle. Various gauge locations and bridge configurations were used to simultaneously measure vertical, lateral, and longitudinal forces along with contact positions.

The data acquisition system is a high-speed, digital system using commercially available computers and related components. Analog signals from the wheelsets are typically sampled at a rate of 300 Hertz using 100 Hertz low pass filters. The data can be processed in conjunction with data measured from the track geometry measurement system and synchronized so that information related to the track geometry and the instrumented vehicle's response to that geometry at any instant in time can be evaluated.

The system incorporates four accelerometers to measure vertical and lateral accelerations experienced by the carbody and the truck with the instrumented wheelsets. Signals from the accelerometers are processed in conjunction with the wheelset data in order to compare acceleration peaks and levels with measured wheel/rail forces.

The use of instrumented wheelsets offers a number of advantages. Instrumented wheelsets provide a means to directly measure instantaneous wheel/rail contact forces. This direct measurement is contrasted to an indirect, or inferred, collection of wheel/rail forces via body motions with displacement or acceleration measurements. The instrumented wheelset system provides for a dynamic measurement that travels with a vehicle, as opposed to wayside measurements made at a fixed track location at one instant in time.

The system not only collects the measured data but also calculates whether there are any exceptions to the vehicle-track interaction (VTI) standards (CFR 49 §213.333) in real time. These are performance based standards using wheel forces and vehicle and truck accelerations, for the additional track classes which allow for train speeds from 90 to 200 mph.

VTI safety standards consist of seven different types of measurements and/or calculations. The requirements are as follows:

1. No wheel shall unload to less than 10% of the static vertical load.
2. The ratio of the lateral force to the vertical force on any wheel (L/V) must not exceed 0.9 for a conservative wheel flange angle of 69 degrees.
3. The ratio of the total lateral force on one side of the truck to the total vertical force on the same side of the truck must not exceed 0.6.
4. The (total) net-lateral force on a single axle must not exceed 50% of the total static vertical force on that axle.
5. The peak-to-peak lateral carbody acceleration must not exceed 0.5 g.
6. The peak-to-peak vertical carbody acceleration must not exceed 0.6 g.
7. The lateral truck acceleration must not exceed 0.4 g root mean squared (RMS) with the mean removed.

A moving window of five feet is used on all of the force measurements which were filtered at 25 Hertz. A moving window of one second is used on the carbody accelerations, while a two second window is used on the truck acceleration. A 10 Hertz filter is used on all of the acceleration measurements.

Since the instrumented wheels were reinstalled at the beginning of February 1999, approximately 20 test runs were conducted between Washington, DC and New York City.

## LAWS OF PHYSICS

It is important to verify that the instrumented wheelsets measure wheel forces and accelerations accurately as the wheels wear. These wheel forces and accelerations were initially confirmed shortly after the wheelsets were installed in 1996. These measurements have been reconfirmed using an NEC test done in June 1999.

The lateral carbody and truck accelerations were compared to theoretical values in order to verify that lateral acceleration, speed, curvature, and crosslevel measurements are all consistent with each other. The theoretical values were derived using simple laws of physics and trigonometry. Figure 1 plots the measured lateral accelerations and theoretical values versus cant deficiency for various curvatures. Cant deficiency is defined as the height that the outside rail in a curve would have to be raised so that the trucks would experience no steady-state lateral acceleration. This close agreement indicates that the acceleration measurements are accurate and consistent with the laws of physics.

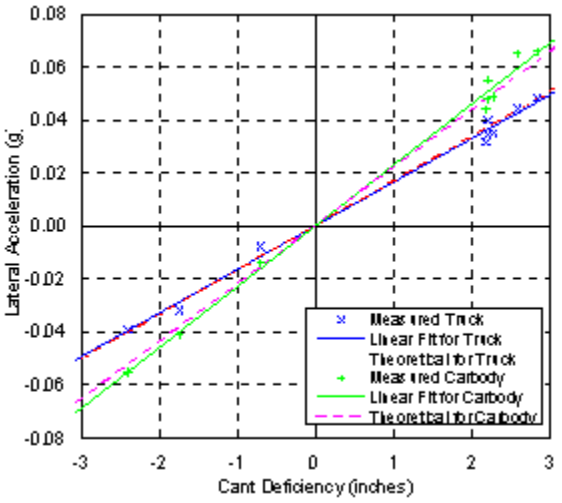


***Figure 1. Lateral Carbody and Truck Acceleration Verification.***

The lateral wheel forces were also compared to theoretical values for various cant deficiency conditions. As shown in Figure 2, this close agreement confirms the accuracy of the lateral force measurements. In addition, the steady-state vertical force measurements have been shown to be accurate on tangent track.

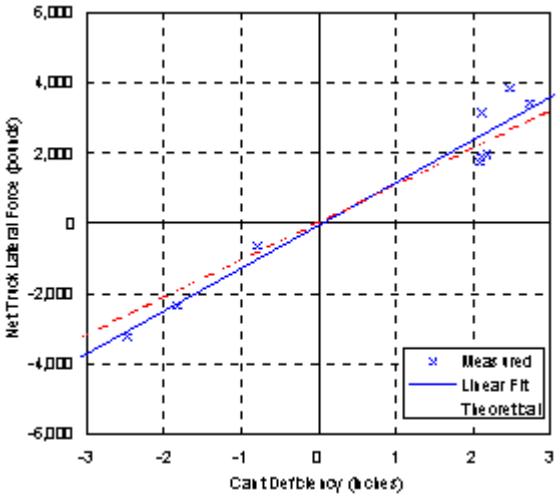


***Figure 2. Net-Truck Lateral Force Verification.***

## VTI Exception Summary

The Vehicle-Track Interaction (VTI) standards were implemented using an offline exception program. The program was run on the round-trip June 1999 NEC test run from Washington to New York City. Various percentages of the VTI limits were used.

Table 2 shows the number of occurrences for each of the seven VTI safety standard requirements at the various thresholds. There were no exceptions at 100% of the VTI limits. The closest value to the VTI limits was a net-axle lateral force on axle 2 at 87% of the limit.

The eleven occurrences exceeding 65% of the VTI limits were investigated further. All of the L/V ratios, truck-side L/V ratios, and net-axle lateral (NAL) force occurrences were at switches. The carbody vertical acceleration also occurred at a switch. The two carbody lateral and the truck lateral RMS occurrences were investigated, but no immediate causes were found.

***Table 2. Exceptions to the Vehicle-Track Interaction Limits on the Northeast Corridor, June 1999.***

| Percent of VTI Limits | 40% | 60% | 80% | 100% |
|---|---|---|---|---|
| Minimum Vertical | 15 | 0 | 0 | 0 |
| Wheel L/V Ratio | 684 | 13 | 0 | 0 |
| Truck-side L/V Ratio | 920 | 5 | 0 | 0 |
| Net-Axle Lateral Force | 75 | 4 | 1 | 0 |
| Carbody Vertical Acceleration Peak-to-Peak | 104 | 2 | 0 | 0 |
| Carbody Lateral Acceleration Peak-to-Peak | 88 | 7 | 0 | 0 |
| Truck Lateral Acceleration RMS | 58 | 1 | 0 | 0 |
| Total | 1944 | 32 | 1 | 0 |

## CONCLUSIONS

The completed tests demonstrated that the instrumented wheelsets are accurately measuring wheel forces and accelerations. A vehicle-track interaction exception report showed that there were no exceptions on the Northeast Corridor between Washington and New York City. The closest value to any limit was a net-axle lateral force at 87% of the VTI limit. Of the highest eleven exceptions, only three were not at switches. These were two carbody lateral accelerations and one truck lateral RMS acceleration.

## ACKNOWLEDGMENTS

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**KEYWORDS:** force verification, instrumented wheelsets, safety, vehicle-track interaction, wheel forces