rMetrix®
Test Plan for
Vehicle Ride Quality

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1 Background

Customer has identified a ride quality issue with a specific vehicle.

In an effort to isolate the root cause of the abnormal operation, Customer wishes to use the rMetrix® Ride Performance Assessment System to study the vehicle's acceleration response characteristics when operating under various operational conditions/configurations (i.e., push/pull, no load, front of consist, back of consist/train set, varying speeds, etc.).

Customer specifically wants to measure and analyze the following vehicle accelerations:

- Carbody Vertical
- Carbody Lateral
- Truck Vertical
- Truck Lateral

From the analysis of the vehicle's acceleration response characteristics, Customer hopes to learn more about the problem and potentially identify a root cause and corrective action.

2 Objectives

The objectives of Customer's study include:

- Record and quantify vehicle acceleration response during operations.
- Identify abnormal or excessive vehicle acceleration response characteristics.
- Correlate abnormal or excessive vehicle acceleration response characteristics to specific vehicle defect(s).
- Determine the corrective action for rectifying the irregular vehicle response characteristics.

All vehicle testing should consider the following general questions:

1. How is the issue characterized? (Oscillatory ride bounce, intermittent vibration bursts, excessive pitch/yaw/roll, excessive noise, etc.)
2. Does the issue occur at a particular speed(s)?
3. Is the issue different or more pronounced in tangent, spiral or curve track segments?
4. Does the issue exhibit under load or without load? If load, in push or pull application or both?
5. Is the issue exclusive to or exacerbated by braking or acceleration events?
6. Does vehicle exhibit multiple symptoms simultaneously?
7. Does the vehicle exhibit the issue consistently each time it is operated?
8. How long has the issue been present?
9. What is the wear and age of wheels and truck assemblies?

3 rMetrix Test Setup

rMetrix is effective in assessing ride quality, comfort and safety in real-time without the need for a dedicated test car or permanently affixed sensor. rMetrix works with your portable computer so that you can perform an inspection at any time and on any vehicle.

The rMetrix system includes a USB tri-axial accelerometer for measuring vehicle accelerations and USB GPS receiver with window mount for recording vehicle position and speed during test. Additional USB accelerometers may be used, and more devices than available computer USB ports may be connected to the computer through the use of a bus powered USB hub. The number of sensor devices is constrained only by the available CPU resources of the computer.

3.1 Vehicle Instrumentation Plan

Since the vehicle is not a perfect ridged body, multiple accelerometers should be used to monitor the acceleration response of the vehicle during operation. Accelerometers should be mounted in different locations about the vehicle to assess vehicle response characteristics. For the planned vehicle testing, dFuzion recommends the use of front and rear truck sensors, and front and rear carbody/cab accelerometers.

dFuzion recommends Customer mount the front carbody accelerometer over the wheel set on the cab floor, closest to the center of the vehicle.

dFuzion recommends Customer mount the front truck sensor directly under the carbody accelerometer on the truck frame if possible.

dFuzion recommends Customer mount the rear truck sensor on the rear truck frame if possible.

dFuzion recommends Customer mount the rear carbody accelerometer over the rear wheel set on the car floor, closest to the center of the vehicle, but directly over the rear truck sensor where feasible.

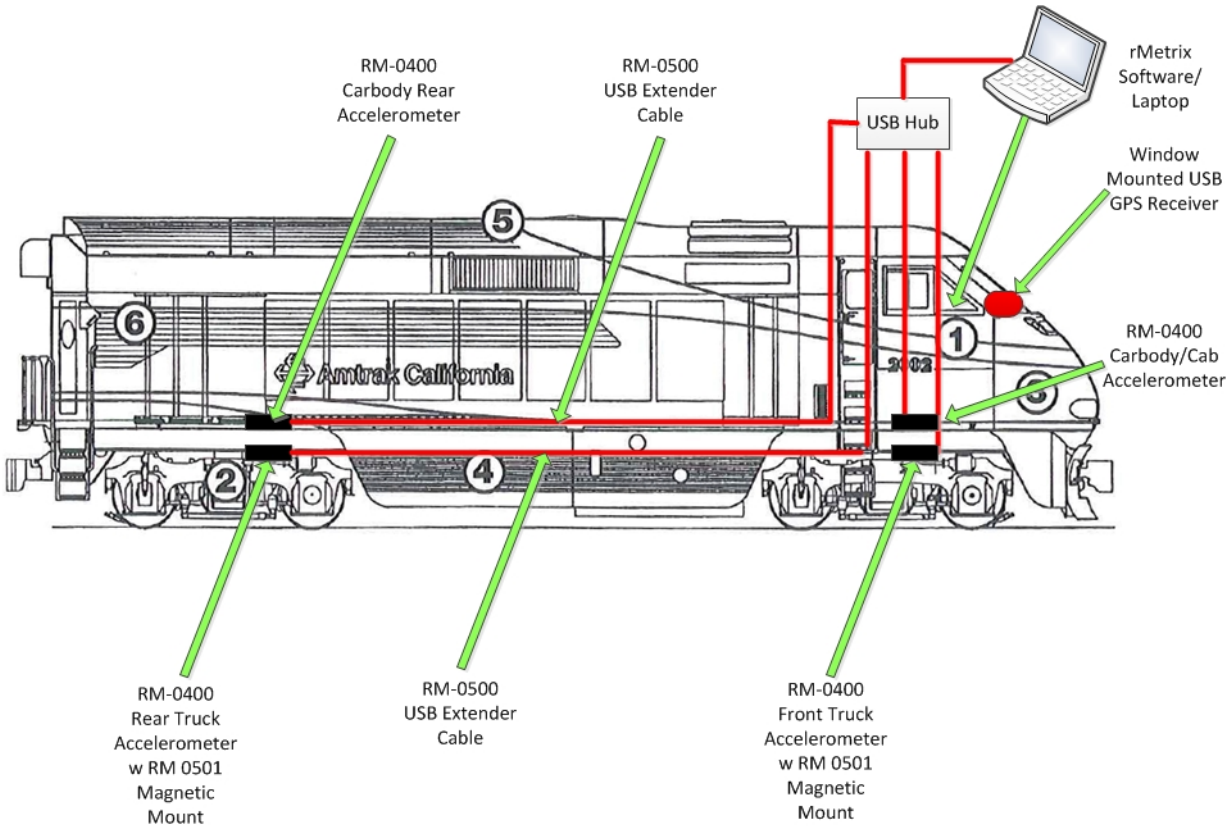

Figure 1 – Recommended Vehicle Instrumentation

3.2 Hardware

3.2.1 Laptop

The rMetrix laptop should be located inside the car and powered by an AC power source where feasible. If Customer has the 74VDC to 120VAC power inverter (optional rMetrix accessory), it can be used to power the laptop computer if 74VDC is the only power option available. **Caution must be exercised when using this device so as not to plug the power plug of this inverter into a 120VAC outlet receptacle.**

Figure 2 - RM-0400 Accelerometer

3.2.2 Accelerometer

The rMetrix accelerometer (RM-0400) may be used inside and outside the vehicle when proper mounting precautions are exercised.

To temporarily mount the accelerometer inside the vehicle, use the supplied two sided tape.

For a permanent mount inside the vehicle, the device may be screw-mounted to a fixed part of the vehicle using the integrated mounting holes on the case. The optional magnetic mount (200 lb. holding power) may also be used.

Figure 3 - RM-0501 Accelerometer Magnetic Mount

To temporarily mount the accelerometer outside the vehicle, the optional magnetic mount may be used. The accelerometer is screwed to the magnetic mount using four screws. The use of Loctite Red (for permanent screw locking) or Blue (for temporary screw locking) is recommended on the screws affixing on the accelerometer to the magnetic mount to ensure they do not vibrate loose during test operations. **If using Loctite Red, heat will be required to remove the screws in the future.**

Figure 4 - RM-0500 Active USB Extender Cable (39')

To extend the distance between the laptop located inside the vehicle cab and the accelerometer mounted outside the vehicle, an active USB extender cable may be used.

Active extenders are either 15’ or 39’ long. The maximum distance between the computer and rMetrix accelerometers is 125’.

The carbody accelerometers may be mounted to the floor of the cab and car using the supplied two sided tape. (See Figure 5) The accelerometers should be mounted over the wheel set on the cab/car floor, closest to the center of the vehicle, but over the respective truck sensors located on the truck frame body where feasible. The accelerometer USB cables shall connect to the USB hub using USB extender cables.

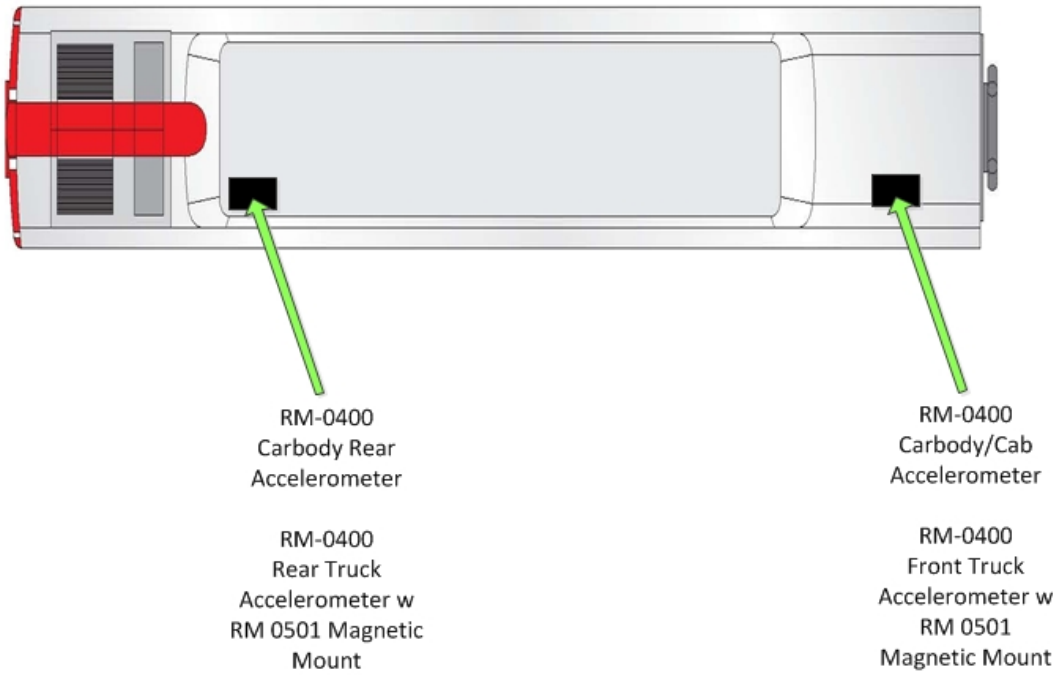

Figure 5 – Carbody and Truck Accelerometer Mounting

Accelerometers may be attached to the truck frame using the RM-0501 magnetic mount. Each accelerometer shall be mounted as level as possible. Direction indication on the accelerometer may be ignored for testing purposes. Wire or cable ties may be used to provide additional sensor loss prevention. **DO NOT ATTACH THE ACCELEROMETER TO THE AXLE OR AXLE BOX, DAMAGE MAY OCCUR TO THE SENSOR.**

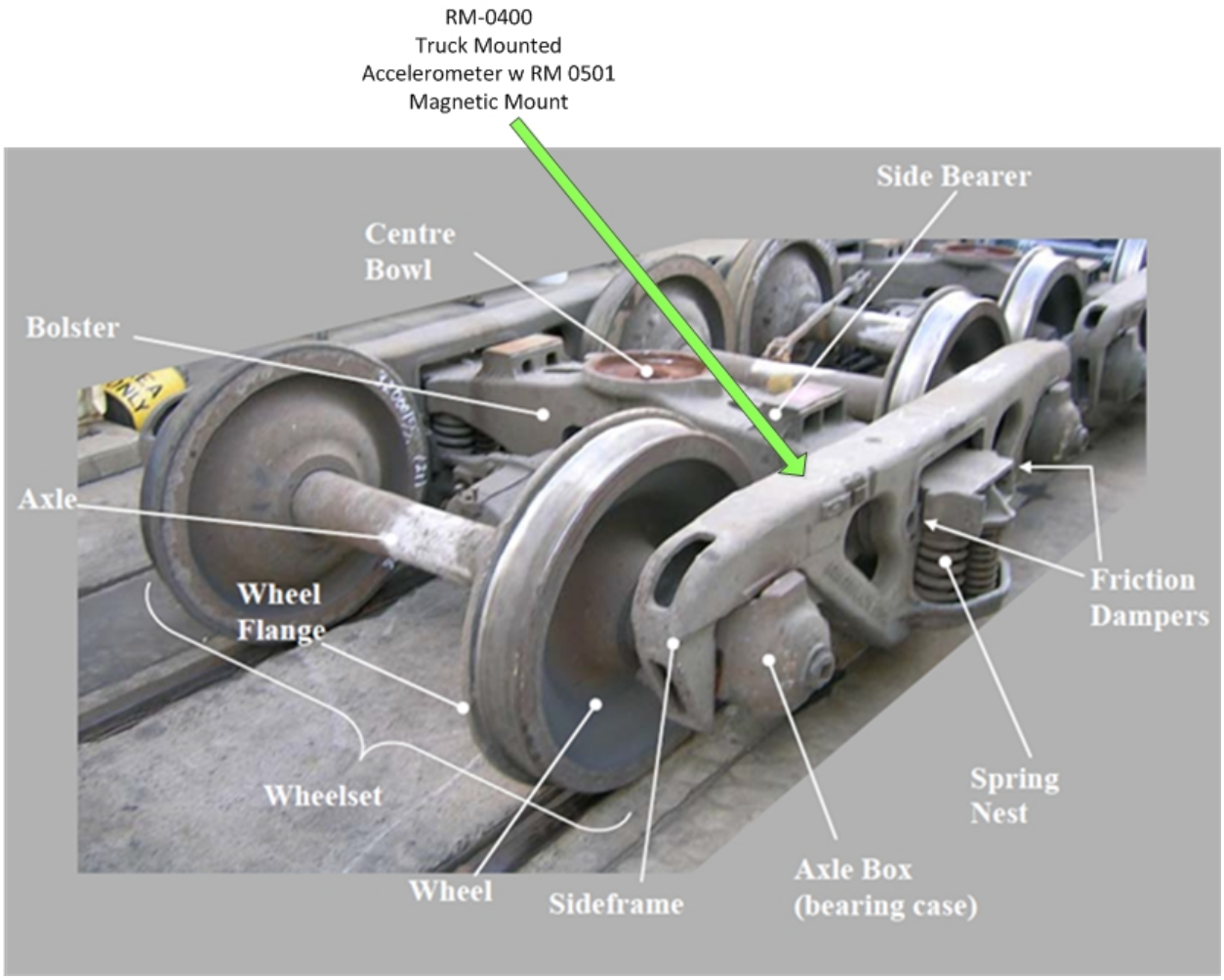

Figure 6 – Truck Mounted Accelerometer

The accelerometer on the front truck should be located directly under the cab carbody accelerometer where feasible. (See Figure 5)

USB cables from the truck sensor should be routed back to the laptop computer in the cab through open windows or doors. Accelerometer and USB extender USB cables shall have a braided protective shield and be affixed to the vehicle using large cable ties or cable clips where feasible. Slack should be left in the cables so as to ensure no damage or premature sensor disconnect is caused by the friction/vibration of the cable against the vehicle during operation. If sensor disconnect occurs, the inspection will close and will need to be restarted. dFuzion recommends using the save calibration set function of the software in the event you need to restart a test while the vehicle is moving.

Any cable interconnects (sensor to USB extender) should be taped (using Duct tape, Heat Shrink or similar) and a “carpenter” or overhand knot used where feasible to prevent premature separation/disconnect. dFuzion has tested the following heat shrink

for sensor to USB extender protection: http://www.cableorganizer.com/heat-shrink/heat-shrink4.htm?gcsct=0ChMIwMDwqtbuugIVSQLnCh3USgAAEAA&gcssku=HS4-100-FT-BK

Figure 7 – Carpenter/Overhand Knot

3.2.3 4 Port USB Hub

dFuzion has tested a variety of 4 port USB hubs for use with the rMetrix system. dFuzion recommends a simple bus-powered USB hub that does not require an external power supply. Rugged hubs such as the Access USB-104-HUB are also good candidates.

Figure 8 - ACCES USB-104-HUB (http://accesio.com/go.cgi?p=/usb/usb-104-hub.html)

A 4-port bus powered USB hub allows the user to connect additional USB accelerometers to the computer.

3.2.4 GPS Receiver

The USB GPS receiver may be mounted in the cab window such that it has open access to the sky. The GPS receiver may be mounted to the cab window using the supplied window mount, or set/taped in the window sill using the supplied two sided tape. The USB GPS receiver connects to the laptop using the supplied USB cable. It may also be operated wirelessly using the Bluetooth protocol.

Figure 9 - RM-0401 USB GPS Receiver

3.3 Software

Since the rMetrix software always records raw acceleration data on each accelerometer regardless of selected test performance standard, the stock FRA highs speed operation performance standards (49CFR 213.333) that are shipped with the software will be appropriate for vehicle testing purposes.

Each accelerometer may be assigned this performance standard when starting a new inspection

- Carbody Vertical, Lateral 49CFR 213.333
- Truck Vertical, Lateral 49CFR 213.333

dFuzion recommends that the higher g range is selected in the rMetrix software for the truck mounted sensor/s (Figure 10).

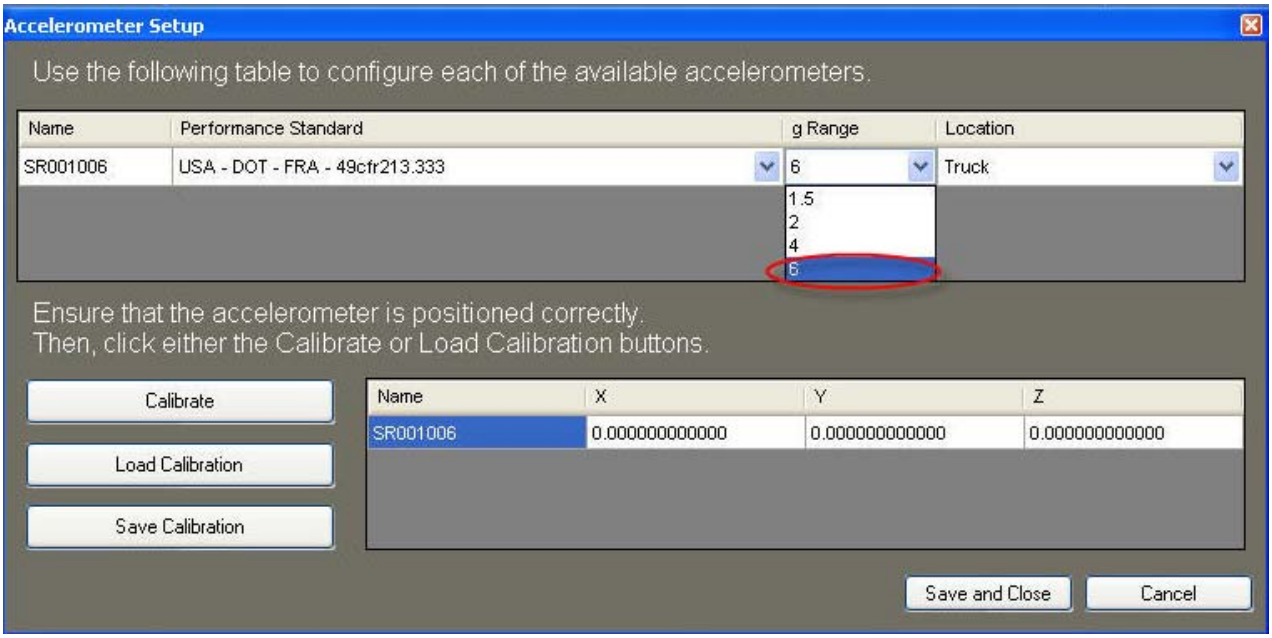

Figure 10 – Setting Truck Sensor g Range

3.3.1 Test Notation

During the testing activities, special notes and information about the test may be notated to assist in the comparative analysis process - post test activities.

1. dFuzion recommends using the manual exceptions or notes capability of the rMetrix software to denote a change in direction of the vehicle along the track.

2. dFuzion recommends using the manual exceptions or notes capability of the rMetrix software to denote a curve. Note - A future rev of the rMetrix software (1.7) will allow storing special areas/location related to particular track geometry (i.e., curves, spiral, etc.) for instant recall and correlation.

3. dFuzion recommends using the manual exceptions or notes capability of the rMetrix software to denote any areas where ride irregularity is experienced.

4. dFuzion recommends using the manual exceptions or notes capability of the rMetrix software to denote any braking or heavy acceleration events.

3.3.2 Offloading Data – Local Computer

The CSV export report allows you to export the GPS and accelerometer data (raw and/or filtered) to CSV format.

To generate a CSV export report, navigate to the CSV Export Report menu item in the Reports menu in the main application screen. The CSV export report can only be run when an inspection is loaded (and not currently in progress).

If an analysis window has been selected in the GPS or Accelerometer Data windows, the CSV export report will only export data from within the defined analysis window. You can use the manual exceptions/notes to select specific windows of the inspection where ride irregularity is experienced. If there is no analysis data window selected, the entire inspection will be exported.

Individual accelerometers and their raw and/or filtered data can be included/excluded from the report using the Select Accelerometer Data dialog box.

The CSV file can then be opened in applications such as Microsoft Excel, Matlab, or LabView for further analysis.

3.3.3 Offloading Data – FTP

To send the entire inspection data to dFuzion, the FTP server settings should be specified by navigating to the Edit->Preferences menu item in the main application window, and selecting the FTP category. The FTP server should be: ftp.rmetrix.com; the Folder should be: Please Contact dFuzion; User Name and Password can be blank.

An inspection can then be uploaded to the specified FTP server by navigating to the File->Upload Inspection and selecting the inspection to upload.

This function is only available when there is no inspection loaded or in progress.

Please note that the Windows firewall may block this process. If this occurs, select Unblock to allow the upload process to proceed.

4 Test Procedure

To achieve the objectives, dFuzion recommends the following test approach:

1. Baseline a known good vehicle for comparative purposes.
2. When testing, try to hold conditions exactly the same between known good vehicle and suspect vehicle.
3. Test vehicles in a stationary position to record static acceleration/vibration response characteristics.
4. Know (in advance) the natural bounce frequency of the vehicle.
5. Know (in advance) any track geometry defects on the test track segment.

Where feasibility exists, try to ensure the following:

- Same vehicle type
- Same position on track (Point A to Point B)
- Same speed profile (Use the rMetrix Speed Profile graph (Figure 15) or real-time speed graph from the good vehicle test as a comparison for setting the suspect vehicle speeds during its test.)
- Same track direction
- Same application and load arrangement
- Same time of day
- Same weather conditions
- Same rail temperature
- Same sensor locations
- Same amount of fuel capacity on each vehicle
- Same number of vehicle occupants
- Note differences in wheel wear

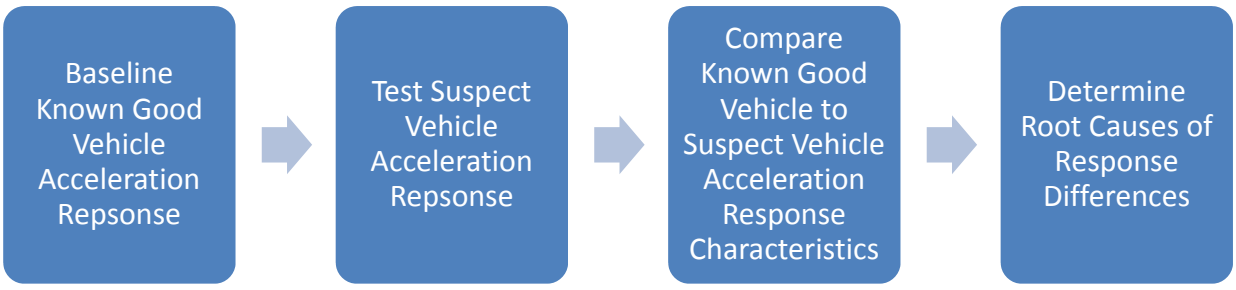

Figure 11 – Test Process

Multiple tests should be performed where possible to ensure measurement repeatability.

5 Post Processing

At the completion of the testing, the raw data from the known good vehicle may be compared to that of the suspect vehicle. Future revisions of the rMetrix software will make this capability automatic from inside the rMetrix software.

Post processing or raw data may currently be accomplished by exporting the raw and filtered rMetrix test data as a .CSV file for further analysis in Microsoft Excel or similar.

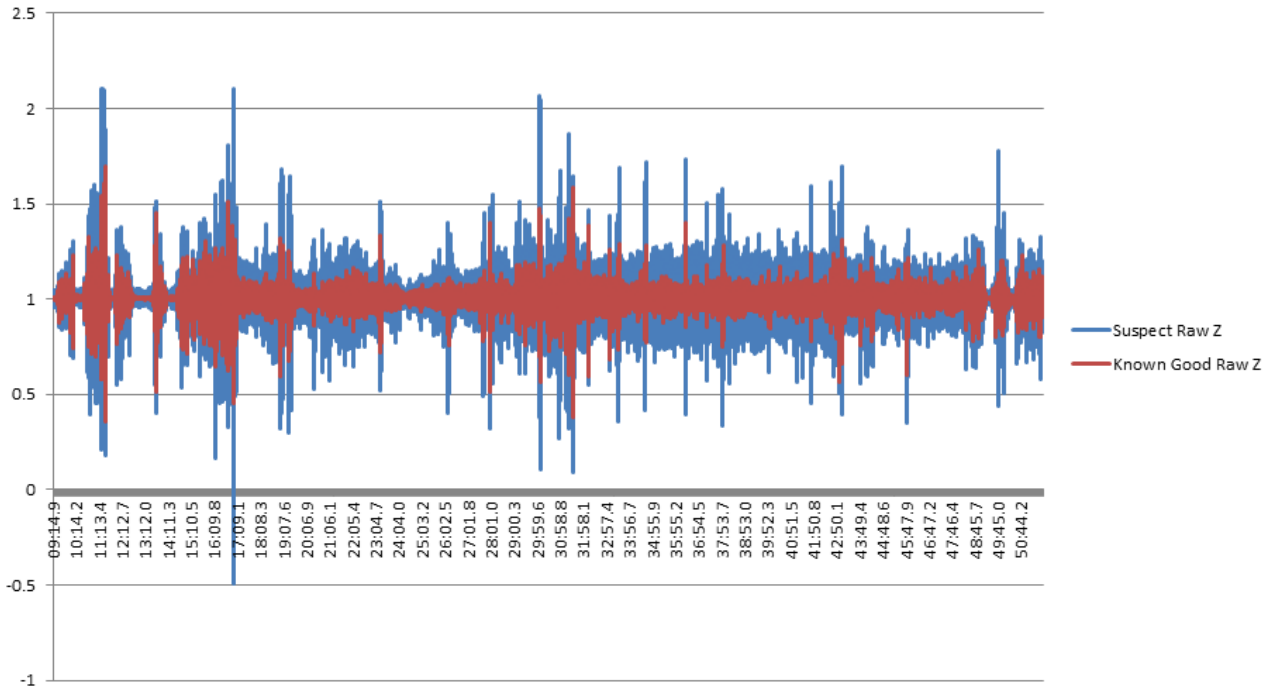

Figure 12 – Post Processing Data Raw Z Axis in MS Excel (Notional)

5.1 Time Series Analysis

The acceleration response time series data recorded by rMetrix presents the forces experienced by the vehicle during operation in the vertical, lateral and forward directions at various locations on the vehicle.

From a comparison of the acceleration response time series of both vehicles (known good and suspect), if significant differences are present, general conclusions may be made in an effort to identify potential root causes of the abnormal condition. Adjustments may be made to the vehicle and repeat testing may eliminate response abnormalities.

An understanding of rail vehicle dynamics is valuable when assessing the raw waveform data. Understating what may cause a vehicle to exhibit a specific

acceleration response/behavior is not simple. rMetrix can only provide raw data and analysis capabilities, the user must use the accumulated data and analysis to postulate further conclusions and potential corrective actions in preparation for vehicle re-test

5.2 Frequency Analysis

Using the Fast Fourier Transform (FFT) analysis, Power Spectral Density (PSD) analysis and the RMS acceleration presented in 1/3rd octave bands capabilities of the rMetrix software, select areas of acceleration irregularity/difference may be studied to determine the strongest frequencies exhibited, their direction of influence and their power affecting vehicle response. Note - one must discount vehicle body natural resonance generally located around 1Hz.

Understanding how the vehicle responds to and exhibits specific frequencies/wavelengths during its operation and how these signals are affect by vehicle suspension components, speeds, and loads is the key to identifying what may be causing the abnormal ride condition and potential corrective actions for elimination.

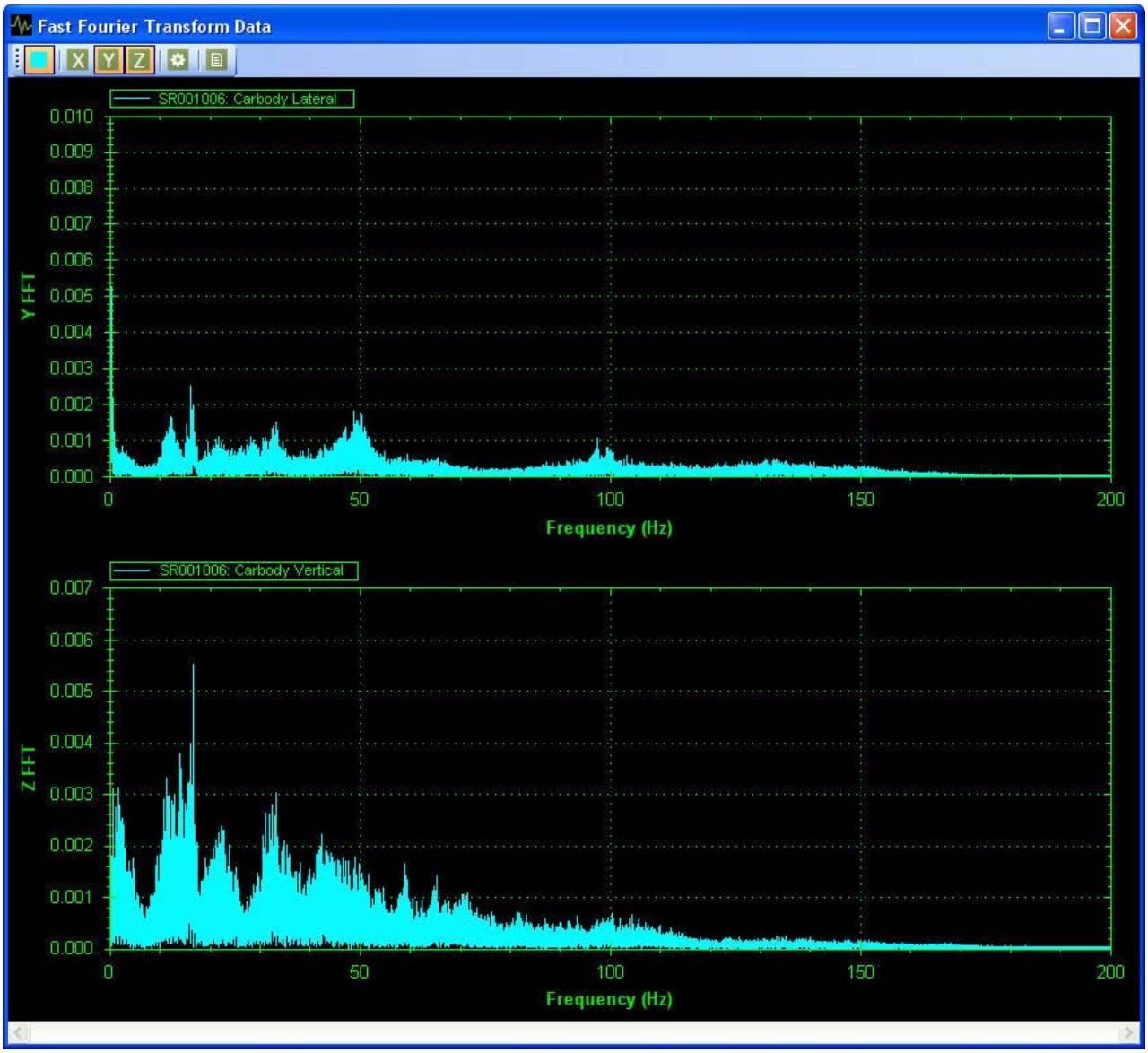

Figure 13 – FFT Plot

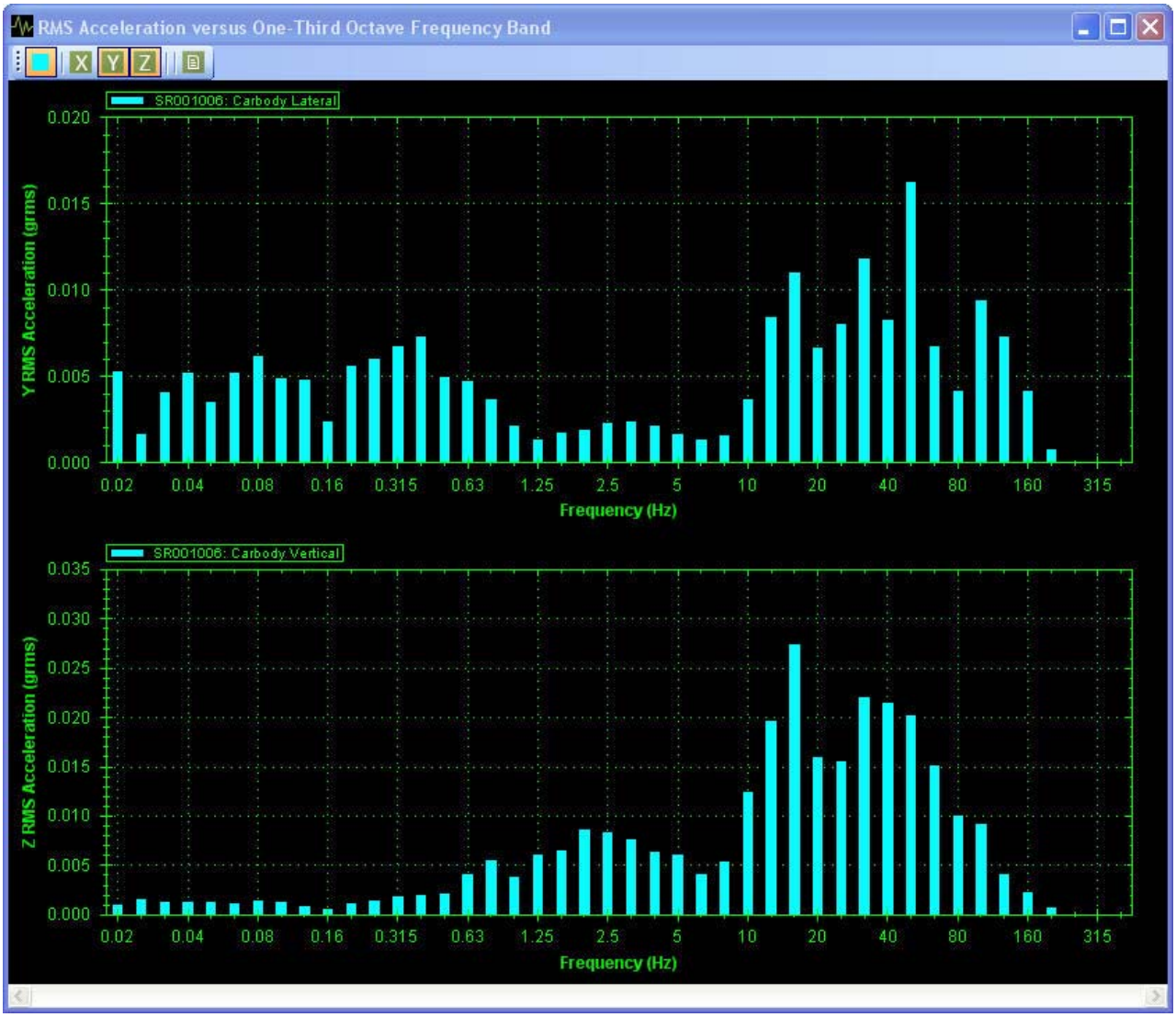

Figure 14 – RMS Acceleration in 1/3rd Octave Bands

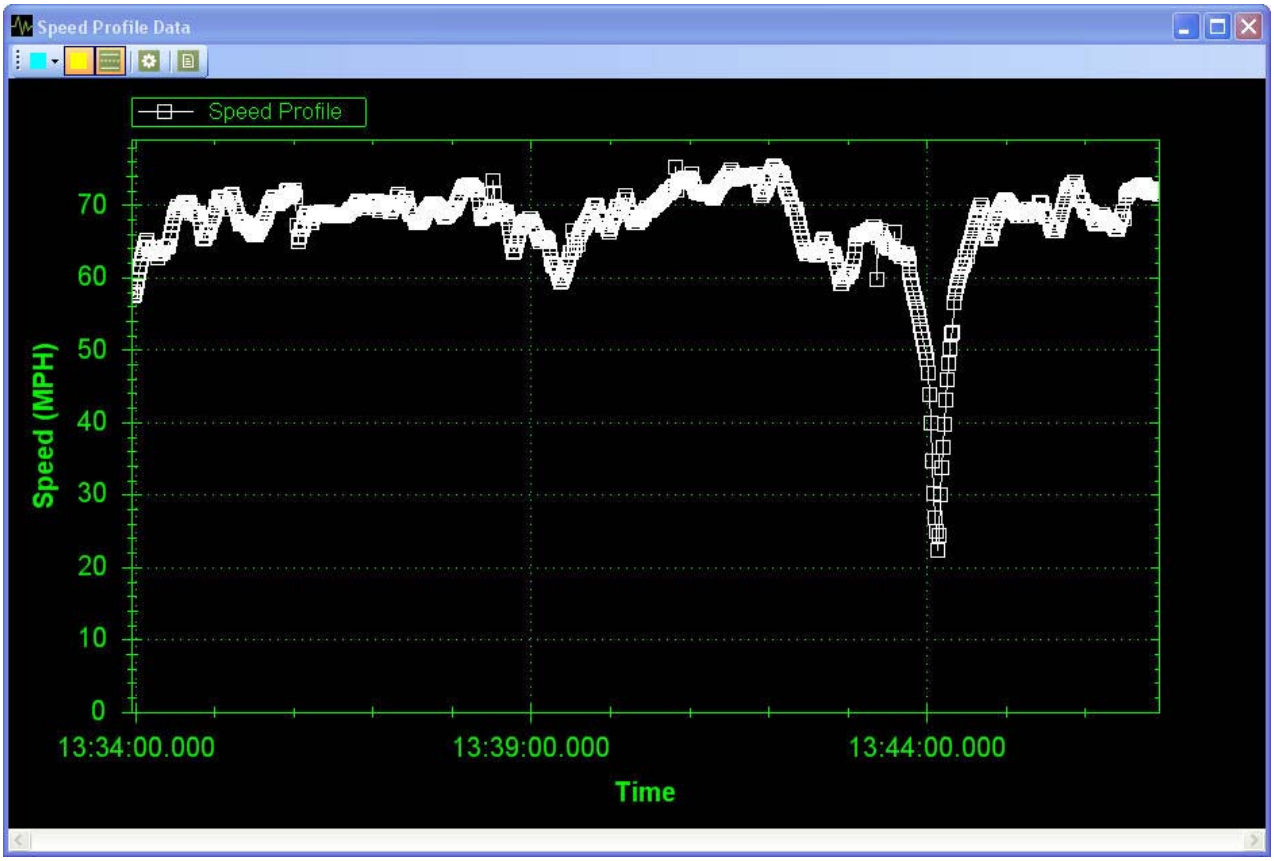

Figure 15 – Vehicle Speed Profile