Improving Track Geometry, Substructure and Ride Quality as a System on the Amtrak Northeast Corridor

by

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Amtrak

ABSTRACT

Track geometry roughness is largely caused by settlement of ballast, subballast and subgrade; components known collectively as track substructure. Ride quality is therefore strongly related to track substructure performance and how well it responds to track geometry correction. Accordingly, Amtrak’s approach to improving ride quality is to view the interaction between vehicle, track geometry and substructure as a system to be optimized. Key to this is determining the types of track geometry error that most affect ride comfort, and how to provide more durable corrections to this error.

Hidden Cyclic Error in Track Geometry Error Waveform and Vehicle Resonance

Amtrak routinely corrects track geometry error that is indicated by the geometry car as mid chord offset error measured over 31-foot, 62-foot and 124-foot chords. However, from a ride quality perspective, the error over wavelengths longer than 124 feet is also important. For this reason, Amtrak has investigated the geometry car measured error over a reconstructed 400-foot chord known as the “space curve”.

Data from track geometry car measurements typically appear as seemingly random waveforms as shown by the right and left rail profile space curves in Figure 1.
Because the error magnitude in this example is not very large relative to the track distance, this would not appear to provide an especially rough ride. However, even waveforms with seemingly small amplitude error can contain cyclic components that cause a buildup of vehicle resonance and result in poor ride quality. An analysis of the profile space curve reveals that such is the case here as observed in Figure 2 which indicates that a relatively strong amplitude error with an approximately 300-foot wavelength is present in the waveform.

Figure 1. Track Geometry Error in Left and Right Rail Space Curve Data

Figure 2. Space Curve Data Filtered to Reveal Cyclic Components in Waveform
Figure 3 shows the resulting filtered data alone and that this 300 foot wavelength component is present in both rails with roughly the same amplitude. This produced a resonant response in the Acela Power Car exciting the carbody bounce mode at approximately 125 mph.

Amtrak has developed a method of identifying the presence of these multiple cycles of harmonic error within track geometry measurement waveforms, but which may not be readily apparent from viewing the geometry error because it is often masked by the complexity of the waveform. Cyclic geometry error is usually of relatively small amplitude and so is often unobserved and left uncorrected by maintenance because the associated mid-chord offset geometry error is typically far less than the safety limit per FRA. However, by using a band-pass filtering function on profile and alignment space curve data from the Amtrak geometry car, the presence and magnitude of any cyclic error becomes apparent.

In addition to identifying the wavelength causing resonance in the Power Car, the cyclic profile error wavelength that produces bounce resonance in the Acela Coach has also been determined and was found to be approximately 170 feet (at 125 mph) as shown in Figure 4. Note that the nearly two-to-one
The difference between resonance-producing wavelengths in the Power Car compared to the Acela coach is due to the difference in carbody mass. The 170-feet and 320-feet wavelengths can both be characterized as “long” wavelength error. This shows the importance of detecting and correcting track error over a considerably longer distance than the longest chord length mandated by FRA for safety (124-feet) if ride quality is to be improved.

Figure 4. Comparison of Bounce Resonance-Producing Cyclic Error Wavelengths for the Acela Power Car and Coach

More Effective and Durable Track Geometry Correction

To improve ride quality Amtrak is also implementing alignment and surfacing methods which are better at detecting and measuring the longer wavelength geometry error that produces a rough ride, and better at providing a smoother and longer lasting geometry correction. One of Amtrak’s high-speed continuous action tampers has been modified with TGCS (Track Geometry Control System) software which is used as an alternative to the software provided originally with the machine. TGCS was developed in Britain where it was found to give improved performance compared to the software provided by the tamper.
manufacturer. Although the testing program has only recently begun the results with TGCS are very encouraging so far.

One aspect of using TGCS is the ability to use Design Over-Lift (DOL) tamping to provide a more durable surfacing compared to conventional tamping. Over lifting the track by a measured amount above what is required for conventional smoothing compensates for the rapid settlement that occurs when traffic resumes following surfacing. It is known that surfacing with a track lift of less than an inch often results in short lived improvements as shown in Figure 5 where the track roughness is in units of standard deviation or SD. In this example, the profile roughness quickly returned after surfacing and 9 weeks of traffic due to ballast settlement. This behavior is often attributed to “ballast memory” which sounds mysterious, but it is nothing more than ballast re-compaction from traffic loading returning the ballast to its pre-maintenance denser state following the disturbance and loosening produced by tamping. If the track is not over lifted this rapid resettlement also provides a return to the original track shape and roughness. However, if track is raised an inch or more the ballast particles can reorient and “lock in” at this new arrangement, and further ballast settlement will be minimal. This behavior is shown in Figure 6 where the smaller track lift results in an almost equal track settlement sometime after resumption of traffic, but the larger lift is more durable with half of it remaining after traffic resumes.

Figure 5. Profile Roughness Returning Shortly After Maintenance

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Figure 6. Influence of Track Lift Applied During Surfacing to Provide a More Stable Geometry

Correction

The amount of over lift to be applied for each tie is calculated by the TGCS program based on a pre-maintenance measuring run of the profile for both rails. The resulting post-maintenance profile appears as shown by the top line in Figure 7. With traffic the initial ballast settlement produces the design profile shown by the solid line. Because further ballast settlement accumulates very slowly the track should stay at this designed profile for a considerable time.

Figure 7. Design Over Lift Tamping Before and After Maintenance Profiles
This designed approach to track surfacing has been shown to provide a much more durable geometry correction compared to conventional smoothing tamping. DOL testing on track with heavy haul freight loading has shown the improved profile to last three times as long compared to conventional surfacing. Further testing on Amtrak will quantify the increase in durability for our track conditions and loading.

Assessing Substructure Condition with Ground Penetrating Radar

Ride quality, track geometry, and the durability of any track geometry correction are heavily dependent upon substructure condition. Amtrak has contracted with HyGround Engineering to assess track substructure conditions using ground penetrating radar (GPR). Track substructure moisture, layer thicknesses, subgrade cross-sectional contour and ballast fouling are among the items that can be evaluated using GPR. The system used is mounted on a high rail vehicle as shown in Figure 8 and the reflecting signals are continuously recorded as the vehicle travels at approximately 25 mph along the track.

![GPR Equipment and High Rail Truck](image)

Figure 8. GPR Equipment and High Rail Truck

The basic principle of GPR operation is shown in Figure 9 where the signal is transmitted into the substructure and the receiver records the attenuated signal as it is reflected back from successively deeper layers of varying dielectric constant values.

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Water provides a particularly strong reflecting signal and can indicate where drainage conditions must be improved.

One of the more critical issues related to ballast performance is the amount of fouling and the related issue of lack of drainage. Highly fouled ballast is a twofold problem for ride quality: it causes rough geometry and it limits the effectiveness and durability of geometry correction. Investigations have shown that ballast on the corridor varies considerably in the amount of fouling along the track. If ballast renewal and replacement by undercutting/cleaning is to be performed it is necessary to prioritize which tracks and track sections have the greatest amount of fouling. GPR data will be used to help establish this program. Figure 10 shows the colorations associated with varying degrees of ballast fouling for four tracks, with green to yellow representing clean to lightly fouled, and red to black as moderately to highly fouled. The middle plot with blue to pink shows the amount of moisture in the ballast. The bottom panel shows the surrounding topography elevations.
Figure 10. Typical GPR Measurements Data for Ballast Fouling (Upper), Moisture Conditions (Middle) and Local Topography (Lower).

Conclusions

Good passenger ride quality relies on track geometry corrections which are only as durable as the track substructure condition allows. Although this is usually difficult to manage because most of the substructure is hidden from view, Amtrak is using methods that allow the track substructure to be “seen” by ground penetrating radar that can assess ballast fouling condition, the presence of water, and the shape and depths of substructure layers. Amtrak is using this and other investigative methods to determine remedial actions that address the specific nature of a persistent geometry error. Improved tamper control and surfacing methods are being developed that will also provide for a more durable geometry correction. By using these improved methods, a significant and longer lasting improvement in ride quality will result.
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Amtrak
Improving ride quality on the corridor

- Ride quality is the car body response to track geometry error
- Most geometry error is due to substructure
- Vehicle, track geometry & substructure is a system
Improving ride quality on the corridor

- Need to correct longer wavelength geometry error
- More durable error correction is also needed
- Track Geometry Control System (TGCS) provided these improvements on Network Rail in UK
- One Amtrak high speed CAT now using TGCS
Finding longer wavelength error
Filtering reveals cyclic error in data
Cyclic long wavelength error

Left & Right Profile Space Curve Error (in.)

Track Footage

Left Rail Filtered

Right Rail Filtered
This cyclic long wavelength error can excite car body.

It’s often difficult for tamper to “see” and treat long wavelength error.

TGCS was developed with this in mind.
Vehicle types respond to different wavelengths
Vehicle types respond to different wavelengths

Track Profile Error Wavelengths That Drive Acela Carbody Bounce
Resonance at 125 mph

Error Amplitude (inches)

Track Distance (feet)

- 320 feet
- 170 feet

- Blue line: Acela Coach @ MP 123.7, T3
- Red line: Acela PC @ MP 127.0, T2
More Durable Geometry Correction
Why does roughness quickly return?

- Pre Maintenance: SD 1.94mm
- Post Maintenance: SD 0.82mm
- 5 Days: SD 1.45mm
- 9 Weeks: SD 1.95mm
Small track surfacing lifts not durable...

...but larger track raises can be durable
This relationship gives design over lift its durability.
Design over lift (DOL)

- DOL shown to last much longer than conventional surfacing
- Improved removal of longer wavelengths also seen
- Ride quality is therefore improved by using better maintenance method
Substructure Assessment with GPR
Ground Penetrating Radar (GPR)

- 400 MHz wide-band GPR antennas
- 3d-Radar™ Step-frequency GPR antenna
- 400 MHz wide-band GPR antenna
Ground Penetrating Radar (GPR)
Ground Penetrating Radar (GPR)

- Fouling
- Moisture
- Topography
Conclusions

- Amtrak is improving ride quality by correcting longer wavelength geometry error
- More durable error correction is also being pursued
- Needed substructure improvements revealed by GPR