ABSTRACT

Successful implementation of high-speed rail (HSR) depends on reliable and efficient turnouts. Turnouts are the control points of the railway network. Their safe, reliable, and efficient operation is critical to the success of any high speed passenger operation.

“Express” HSR systems, as defined by the Federal Railroad Administration (FRA), are expected to include dedicated grade-separated passenger train infrastructure and systems that permit operating speeds in excess of 150 mph (241.5 km/h). While successful express HSR turnout designs exist today, those optimized for dedicated passenger train service do not include U.S. rolled rail sections and have not been successfully demonstrated under U.S. designed and manufactured wheelsets. While previous FRA and Transportation Research Board TRB research have focused on making improvements to existing “emerging” and “regional” HSR turnout
designs (for speeds below 150 mph (241.5 km/h)), few, if any investigations have considered leveraging the “service-proven” experiences learned in other parts of the world. The development of an American express HSR turnout will serve as an “end-of-scale” benchmark, which should provide an invaluable reference for future developments including emerging and regional HSR systems.

The FRA sponsored the title project in March 2012. The primary objective of the research was to investigate key elements of HSR turnout design and perform vehicle/track multi-body simulations using NUCARS® modeling (NUCARS is a registered trademark of Transportation Technology Center, Inc., Pueblo, CO) to validate and compare design alternatives. This paper presents the results of this research and also serves to help stakeholders, who may not be familiar with differences in turnout design approaches, build a better understanding of key design elements.

INTRODUCTION

The Federal Railroad Administration (FRA) contracted with voestalpine Nortrak to conduct a high-speed rail (HSR) research project titled “High Speed Rail Turnouts for the USA.” The project was divided into two parts; the first part of the project involved the development, comparison, and validation of multiple “Express” HSR turnout design variations, the second part consisted of the development of installation plans and specifications for the same into the FRA’s existing high-speed Railway Test Track (RTT) near Pueblo, CO. While the scope of the current project is limited to design only, industry stakeholders keenly await opportunities to complete installations and commence with field testing and verifications.

As outlined in the FRA’s “Vision for High-Speed Rail in America,” the development of “Express” HSR systems with shared trackage is not part of current national planning. Express HSR systems are currently expected to consist of dedicated grade-separated passenger train infrastructure and systems with operating speeds up to 110 mph (177.1 km/h) on diverging lines and 220 mph (354.2 km/h) on main lines. Prototype turnouts are to be developed and modified as required for two separate installations on concrete-tie ballasted track and concrete slab track.

While this study will focus on the development of express HSR turnouts, the benefits of this research are expected to extend to the development of similar designs for “emerging” and “regional” HSR systems [1]. Both of these lower speed levels of HSR are expected to include infrastructure that will be shared with existing freight operations. Several HSR passenger rail systems in Europe and Asia do share tracks with freight trains, but the U.S. freight system includes significantly higher loadings and more severe operating conditions. In this respect, the development of an express HSR turnout optimized for high-speed passenger train service and sufficiently robust to accommodate U.S. freight service is unprecedented.

One of the primary objectives of this study is related to leveraging the “service-proven” experiences learned in other parts of the world by incorporating most, if not all, of these design aspects into an American version of a HSR turnout. The development of an American “Express” HSR turnout will serve as an “end-of-scale” benchmark, which should provide an invaluable reference for the development of turnouts for emerging and regional HSR systems.
HSR TURNOUT GEOMETRY AND DESIGN PARAMETERS

Initially, four types of HSR turnout geometries were prepared for evaluation. Layouts for a Spiral-Curve-Spiral (S-C-S) with Kinematic Gage Optimization (KGO), two versions of Spiral-Spiral (S-S) with KGO, and a “Presteer” S-C-S turnout were developed as representative designs.

Table 1 compares the turnout geometries, design parameters, and components. Three of the designed turnouts, S-C-S (No. 42.8), S-S (No. 49.6), and Presteer S-C-S, were selected to be further scrutinized through NUCARS modeling. The S-S No. 44.2 turnout, which has the shortest turnout length, was abandoned because two design parameters, the cant deficiency and cant deficiency change rate, exceeded the criteria limits commonly used for HSR turnout design.

Table 1. Turnout Geometries, Design Parameters and Components

<table>
<thead>
<tr>
<th>Turnout Geometry</th>
<th>Turnout No. (AREMA)</th>
<th>Radius</th>
<th>Cant Deficiency</th>
<th>Cant Deficiency Change Rate</th>
<th>Entry Jerk</th>
<th>Actual Lead (PS** to Theo***</th>
<th>X Over-length (TS to TS‡)</th>
<th>Switch Point Length</th>
<th>Quantity of Switch Machines in Switch Point</th>
<th>Quantity of Ties per Turnout No.</th>
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</thead>
<tbody>
<tr>
<td>S-S (C3A2) Ds1</td>
<td>No. 49.6 A10-49570</td>
<td>34,000 ft/16,200 ft</td>
<td>3.00 in</td>
<td>2.34 in/s</td>
<td>5.00 in/s</td>
<td>439.25 ft</td>
<td>1,238.43 ft</td>
<td>192.33 ft</td>
<td>7</td>
<td>325</td>
</tr>
<tr>
<td>Ds2</td>
<td>No. 44.2 A10-42800</td>
<td>34,000 ft/13,050 ft</td>
<td>3.66 in</td>
<td>3.36 in/s</td>
<td>5.47 in/s</td>
<td>412.27 ft</td>
<td>1,136.18 ft</td>
<td>182.44 ft</td>
<td>6</td>
<td>289</td>
</tr>
<tr>
<td>S-C-S</td>
<td>No. 42.8 A10-42800</td>
<td>34,000 ft/16,200 ft</td>
<td>3.00 in</td>
<td>2.36 in/s</td>
<td>5.36 in/s</td>
<td>418.99 ft</td>
<td>1,138.63 ft</td>
<td>184.53 ft</td>
<td>6</td>
<td>290</td>
</tr>
<tr>
<td>Presteer† (C2A1) Spiral + Circular Curve + Spiral</td>
<td>No. 42.8 A10-48201</td>
<td>34,000 ft/16,200 ft†</td>
<td>3.00 in</td>
<td>2.36 in/s (spiral area)</td>
<td>--</td>
<td>430.99 ft</td>
<td>1,165.50 ft</td>
<td>184.53 ft</td>
<td>7</td>
<td>296</td>
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</table>

* 1 inch = 25.4 millimeters; 1 foot = 0.305 meters
** PS = point of switch
*** Theo = theoretical frog point
‡ TS = the connection point of tangent and spiral track
† Presteer is used in the switch point area

Table 2 lists the design parameter limits used for HSR turnout design in this study. All proposed turnouts, except the S-S No. 44.2 turnout, comply with these limits. Although comparing designs of similar footprints is preferred, the design criteria established to guide base concept design required the S-S layout to be lengthened. The S-S No. 49.6 turnout has the longest turnout length, but the lowest cant deficiency change rate. Figure 1 shows the S-C-S No. 42.8 turnout design sketch and parameters.

Table 2. Turnout Design Parameters and Standard Limits

<table>
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<tr>
<th>Design Parameters</th>
<th>Limits</th>
<th>Standards</th>
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<td>AREMA Chapter 5 [3]</td>
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<tr>
<td>Maximum Cant Deficiency</td>
<td>3.34 in/s</td>
<td>BS EN 13803-2 [4]</td>
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<tr>
<td>Change Rate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entry Jerk</td>
<td>5.91 in/s</td>
<td>BS EN 13803-2 [4]</td>
</tr>
</tbody>
</table>

* 1 inch = 25.4 millimeters
Figure 1. S-C-S No. 42.8 Turnout Design Sketch and Parameters

It is important to note here that, in general terms, longer footprint layouts of similar designs lead to higher comfort and safe diverging route speeds. Comparing similar length S-C-S and S-S layouts, and using the criteria established in Table 2, it should be noted that the latter design is required to be lengthened. It is conceivable then that longer footprint versions of the two S-C-S layouts used in this study would perform marginally better than the considered design lengths.

The Presteer switch was originally designed for low speed North American turnouts that usually have a noticeable kink angle [4]. The concept has been described in the literature review section of the FRA project final report [5]. The main difference between the Presteer S-C-S turnout and the base design S-C-S turnout is the switch part. By manipulating alignment, gage, and running surface profiles ahead of the point of switch, wheelsets may be presteered to a negative angle of attack ahead of the switch point, so the wheel runs away laterally from the switch point to decrease wheel-rail (W/R) lateral force and damage to the switch point.

However, the Presteer switch point is the longest one among all designs due to the switch blade extension beyond the traditional point of switch.

All three of the proposed layouts considered in this project include the following general design features:

- KGO through the switch entrance
- Asymmetric tangential geometry switch with near zero entry angle
- Canted rail (1:40) throughout both main line and diverging routes
- Curved geometry moveable point frog (MPF)
- Elastomeric base plate support
VEHICLE AND TRACK MODEL

Two generic vehicle models, including a power car and a coach car model, were used for simulations. These two vehicle models were modified based on Acela train power car and coach car models, which had been used previously in several studies. Original Acela train model parameters were either measured or calculated based on manufacturers’ drawings. The Acela train power car and coach car were previously tested on the RTT at TTCI at speeds up to 170 mph (273.7 km/h).

The Acela train power car truck has relatively stiff primary (radial arm) and secondary (coil spring) suspensions, while the coach car’s primary (radial arm) and secondary (air bag) suspensions were relatively soft except that the power car lateral primary suspension stiffness was lower than that of the coach car.

The tilting mechanism in the coach car model was turned off to make the coach car model more generic. The power car and coach car models were considered to be representative of rigid and soft suspension trucks commonly used in HSR systems. The axle load for the power car and the coach car were 50 kips (22.7 tonnes) and 33 kips (15 tonnes), respectively, representing a wide range of axle loads in HSR systems.

The power carbody was modeled as a flexible beam with torsional modes; the coach carbody was modeled as a flexible beam with torsional modes and vertical bending modes since the coach carbody length is longer than that of power car.

Three types of wheel profiles, APTA 240, Acela, and European standard S1002, were used in the simulation to evaluate wheel profile effects on turnout dynamic performances.

A one-layer track model in NUCARS, including two 276-foot-long (84.18 meter) flexible rails with spring/damper connections to the ground, was used for track modeling. Each rail was modeled as Euler-Bernoulli beams.

The track model in NUCARS consists of one or several segments of the track element. The track element is repeated as the vehicle runs out of the end of the track element, which makes the track appear endless to the vehicle.

The stock rail used for the turnout simulations was the standard AREMA 136RE rail. The switch and MPF profiles varied along track based on the cross section profiles. The profile variation was conducted by using the NUCARS double rail model.

DYNAMIC SIMULATION RESULTS

The HSR turnouts considered in this project are designed to be installed on slab or ballast track foundations. Simulations were conducted by using a power and a coach car model running through the three candidate turnouts, over slab and ballasted track foundations, on the diverging line crossover, and on the main line facing and trailing running directions. One FRA Class 9 track vertical perturbation was implemented on the slab track near the field welded joint ahead of the switch point for simulations in the diverging route crossover and main line facing point
movements. The perturbation has a triangle wave shape with 0.5-inch (12.7 mm) vertical amplitude and 31-foot (9.4-meter) chord length. The same perturbation, located on the field welded joint ahead of the frog point, was used for the simulation in the main line trailing point direction.

Two adjacent perturbations were used for turnout simulations on ballast track, representing track perturbation conditions worse than what may be expected on slab track. However, the two perturbation amplitudes and relative positions still meet the FRA Class 9 track maintenance standard.

The first perturbation starts on the left side rail of the track with a downward amplitude, then the second one starts at a distance of 14 ft (4.27 m) from the end of the first perturbation on the right side rail with an upward amplitude. The arrangement of these two perturbations creates cross-level perturbations between the first and last axles in each truck in addition to vertical perturbations.

The car dynamic performances were evaluated by using FRA 213.333 Vehicle/Track Interaction Safety Standards [6] and ISO-2631 ride quality criteria [7].

Figure 2 shows the maximum wheel lateral over vertical (L/V) force ratios of the power car with APTA 240 wheel profiles running through the slab track diverging line crossover. The maximum wheel L/V ratios increased with speed, however, were far below FRA 213.333 track safety standard limits on the three turnouts.

Figure 3 shows the wheel L/V ratio time histories of the power car with APTA 240 wheel profiles running through the slab track diverging line crossover at 120 mph (193.2 km/h). The maximum wheel L/V ratios usually occurred on the switch entry area of the left rail due to flange contact; flange contacts also occurred on the switch exit area of the right rail with peak L/V ratios, but these peak L/V ratios were filtered out by the 5-foot filtering window.
Figure 2. Power Car Wheel L/V Ratios, APTA 240 Wheel, Slab Track, Diverging Line Crossover

Figure 3. Power Car Wheel L/V Ratio Time Histories, APTA 240 Wheel, Slab Track, Diverging Line Crossover, 120 mph (Black Line: S-C-S, Green Line: S-S, Red Line: Presteer S-C-S)
Figure 4 shows the maximum wheel L/V ratios of the coach car with APTA 240 wheel profiles running through the slab track diverging line crossover. All maximum wheel L/V ratios on the three turnouts were far below FRA 213.333 track safety standard limits. The maximum wheel L/V ratios on the Presteer S-C-S turnout was the lowest one among the three turnouts at all simulated speeds due to axle steering ahead of the traditional point of switch.

Figure 5 shows the wheel L/V ratio time histories of the coach car with APTA 240 wheel profiles running through the slab track diverging line crossover at 120 mph (193.2 km/h). The coach car wheel flange contacts also occurred on the switch entry area and switch exit area with peak L/V ratios.

![Graph showing wheel L/V ratios at different speeds](image)

**Figure 4. Coach Car Wheel L/V Ratios, APTA 240 Wheel, Slab Track, Diverging Line, Crossover**
Figure 6 shows that the lateral movements of the power car and the coach car generally followed the turnout alignment geometry; however, the power car axles oscillated laterally with about 200-foot wave length except when running on the Presteer S-C-S turnout. The oscillations amplitudes gradually decreased and did not reach the levels of hunting movements or the limits of stable movement cycles. The softer radial arm lateral stiffness and damping characteristics of the power car could be one of the reasons for the axle oscillations. The Presteer switch steered the axles in the switch entry area so the axles moved away from the switch point, which caused less impact on flange contact and smaller excitation of axle lateral movements.

The coach car axles followed the turnout track alignment geometry without oscillations, indicating the suspension stiffness and damping are sufficient to prevent axle instability.
Figure 7 shows that the maximum carbody lateral accelerations root-mean-square (RMS) values of the coach car with APTA 240 wheel profiles running on slab track for the diverging line crossover were all below 0.63 g, the ISO-2631 “a little uncomfortable” perception level limit. Table 1 shows that the carbody lateral accelerations RMS values on the S-S turnout were the lowest among the three turnouts at all speeds due to its lowest cant deficiency change rate and entry jerk.
Figure 7. Power Carbody Lateral Acceleration RMS, APTA 240 Wheel, Slab Track, Diverging Line, Crossover

Figure 8 shows the power car with S1002 wheel profiles hunts at 120 mph (193.2 km/h) with a shorter wave length (58 ft (17.7 m)) than with APTA 240 (about 200 ft (610 m)) and Acela (about 200 ft (610 m)) wheel profiles. The coach car axle with S1002 wheel profiles was stable at 120 mph (193.2 km/h). In addition to the soft lateral suspension stiffness in the power car, the following two factors contribute to axle hunting:

- High W/R contact conicity (>0.1) generated from S1002 wheel/AREMA 136RE-10 rail
- Tight W/R clearance

The overall dynamic performances of the simulated two car models with S1002 wheel profiles deteriorated at speeds higher than 100 mph (161 km/h) due to axle instability.
Figure 8. Power Car Axle Lateral Displacement Time History, S1002 Wheel, Slab Track, Diverging Line, Crossover, 120 mph (Black Line: S-C-S, Green Line: S-S, Red Line: Presteer S-C-S)

Figure 9 compares the W/R contact equivalent conicity. The S1002 wheel/AREMA 136RE-10 rail combination generates the largest W/R contact conicity and a negative slope of equivalent conicity on tread contact; all other W/R combinations generate positive slopes of equivalent conicity on the tread. All W/R equivalent conicities, except the S1002 wheel/AREMA 136RE-10 rail, are less than 0.1 at 0.118 inch (3 millimeters) lateral displacement location, as recommended by The Interoperability of the Trans-European High Speed Rail System, Draft Technical Specification for Interoperability [8].

Polach [9] investigated the effects of nonlinearity of the equivalent conicity function on car instability performance; he concluded that a high equivalent conicity with negative slope of equivalent conicity function, such as the European standard S1002 wheel/AREMA 136RE-10 rail combination, could result in car instability with supercritical Hopf bifurcation characteristics.
Figure 9. Alternative Wheels Equivalent Conicity

The W/R contact geometry has effects not only on conicity lateral stability, but also on curving and wear performances. Comparisons of the W/R flange contact position in Figure 10 shows:

- The Acela wheel profile is conformal to the AREMA 136RE-10 rail in flange root contact, which can reduce flange wear by distributing wear evenly.
- The S1002 wheel profile matches the UIC60 rail on flange root area better than AREMA 136RE-10 rail.
- Two-point contact occurs for the S1002/AREMA 136RE-10 W/R combinations when in flange contact with a flange root gap between wheel and rail; two-point contact decreases axle steering capability on curving.
CONCLUSIONS AND RECOMMENDATIONS

Car Dynamic Performances on Turnouts

- The car dynamic performances of the two car models (power and coach cars) with APTA 240 wheel profiles running on the diverging line crossover of all of the proposed turnouts (including slab and ballasted track) meet FRA 213 track safety standard limits at speeds up to 120 mph (193.2 km/h), the target design speed for turnout diverging moves.
- The car dynamic performances of the two car models (power and coach cars) with APTA 240 and Acela wheel profiles running on slab track for the main line of the turnouts meet the FRA 213 track safety standard limits at speeds up to 240 mph (386.4 km/h), the target design speed for turnout main lines.
- The carbody accelerations of the two car models (power and coach cars) with APTA 240 wheel profiles running on slab track for the diverging and main lines of all of the proposed turnouts meet ISO-2631 ride quality “a little uncomfortable” criteria values at target design speeds.
- The car dynamic performances on ballasted track for the main line for all of the proposed turnouts with APTA 240 and Acela wheel profiles meet FRA 213.333 track safety standard limits at speeds up to 180 mph (289.8 km/h); the performance deterioration was
caused by extreme vehicle suspension conditions and ballast track perturbations, indicating the importance of HSR car suspension system optimization and effective track maintenance.

- The dynamic performances of the two cars modeled with the S1002 wheel profiles deteriorated at high speeds due to truck hunting.
- The Presteer S-C-S turnout generally provides the lowest L/V ratio, truck side L/V ratio, net axle L/V ratio, and wheel unload ratio on the diverging route among the three proposed turnouts due to its axle steering capability.
- The S-S turnout provides the best ride quality on diverging route among the three proposed turnouts due to its lowest cant deficiency change rate and entry jerk.
- The S-S turnout overall provides better dynamic performances than the S-C-S turnout on diverging lines.
- The Presteer S-C-S turnout provides the lowest wear indices on the diverging route among the three proposed turnouts due to its axle steering capability.
- The wing rail shape matches the APTA 240 wheel profile in hard flange root contact condition and generates less contact stress than that with Acela wheel profiles.
- The wing rail with a 1:40 slope top decreases tread contact stress by 50 percent compared to that with a flat top.

Car Lateral Stability

- The hunting speed of the power car implemented with the standard S1002 wheelset is lower than that with the APTA 240 and Acela wheel profiles.
- The standard S1002 wheelset with 53.543 inches (1,360 mm) wheel back-to-back distance and AREMA 136RE-10 rail combination generates the highest tread contact conicity and negative slope of conicity.
- The standard S1002 wheelset back-to-back distance is about 0.2 inch (5 mm) wider than the existing Acela wheelset. With 0.2 inch (5 mm) back-to-back distance decrease, the S1002/AREMA 136RE-10 rail combination generates similar equivalent conicity and hunting speed as the Acela/AREMA 136RE-10 rail combination.
- Two-point contact occurs for the S1002/AREMA 136RE-10 combination when in flange contact with a flange root gap between wheel and rail, indicating a less favorable wear and curving performance than with the APTA 240 and Acela wheel profiles.

The following recommendations are proposed for turnout and vehicle design optimizations:

- Change the frog running surface flat top to 1:40 slope to match the 1:40 wheel taper to reduce tread contact stress
- Install a guard rail on the diverging route to prevent:
  - Hard flange root contact on wing rail and frog point
  - Excessive wear, fatigue, and most importantly, wheels picking the frog point
- Vehicle parameter optimizations, including tuning suspension systems and modifying wheel profiles, are essential for improving car curving performances on the turnout diverging route and stability on the main line at high speeds.
ACKNOWLEDGMENTS

Thanks to the FRA for providing funding and for their active participation in this study. Active participation and guidance from both vehicle and track systems engineers from the John A. Volpe National Transportation Systems Center is also greatly appreciated.

REFERENCES

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FRA BAA HIGH SPEED TURNOUT DESIGN PROJECT

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Blaine O. Peterson, P.E., voestalpine Nortrak Inc.
Sung Lee, Federal Railroad Administration
Objectives

Design “Express” high-speed rail (HSR) turnouts with detailed drawings and specifications for their inclusion in an appropriate test facility.

- Through speeds of up to 220 mph
- Diverging route speeds of up to 110 mph

Approach

“Express” HSR design elements:
- Spiral and longer curved geometries;
- Tangential geometry switch entries;
- Kinematic Gauge Optimization;
- Elastomeric base plate support;
- Asymmetric switch points;
- Slab track turnout systems

American innovations:
- Robust, “T” rail moveable point frogs;
- Explosive depth hardened manganese steel components;
- Larger than UIC-60)136RE rail section;
- Robust, service-proven AREMA design concrete ties;
- FRA/PCA plain line slab track design

Design Concept

A #39.6 10,000m/4,000m 100 mph service-proven design used on German and Taiwan projects as the starting point.

Modified to meet the following additional anticipated requirements:
- Through speeds of up to 220 mph and diverging speeds of up to 110 mph
- CHSRA TM 2.1.3 - Turnouts and Station Tracks
- AREMA - Chapter 5 - Unbalance Limit
- EN 13803-2 Track Alignment Design Parameters - 2010-04-01
- CHSRA requirement for European Technical Specification Interoperability (TSI) compliant rolling stock

Design Parameters and Criteria

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<tr>
<th>Design Parameters</th>
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<th>Standards</th>
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<td>Maximum Cant Deficiency</td>
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<td>AREMA Chapter 5</td>
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<td>Maximum Cant Deficiency Change Rate (CDCR)</td>
<td>3.34 in/s (85 mm/s)</td>
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<td>Entry Jerk</td>
<td>5.91 in/s (150 mm/s)</td>
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**Design Comparison**

<table>
<thead>
<tr>
<th>Turnout Geometry</th>
<th>T/No Number (AREMA)</th>
<th>Radius (feet)</th>
<th>Curve Deficiency (inches)</th>
<th>Ring-work (inches)</th>
<th>Actual Lead (inches) to Turnout</th>
<th>X-over length</th>
<th>Switch Point Length</th>
<th>Switch machines in yard</th>
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<td>S-C-S</td>
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<td>5.31</td>
<td>149.68</td>
<td>300</td>
<td>90</td>
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- CDCR not within EN limit
- Inconsistent with AREMA 3” limit

**Spiral-Curve-Spiral Turnout**

- Consistent with AREMA 3-inch limit
- CDCR within EN limit

**Spiral-Spiral Turnout**

- Spiral Length = ~408 feet
- Turnout Length = ~620 feet

- Both S-C-S and S-S turnouts implemented in HSR
- No consensus in the industry related to the basic geometry of high-speed turnouts
- Design criteria requires the S-S layout to be lengthened

**Presteer Switch Concept**

- Originally designed for low speed N.A. turnouts with noticeable kink angle
- Manipulating alignment, gage, and running surface profiles ahead of the point of switch
- Wheelsets steered to a negative angle of attack (AOA) ahead of switch point
- Decrease wheel/rail (W/R) lateral force and damage on the switch point
- Longer switch point

**Diverging Line Turnout Curvature**

**Track Perturbation Location**

- Class 9 Track vertical perturbation, located on the field welded joint ahead of switch point, used for simulation in diverging line crossover and main line facing direction
**Vehicle Model**
- Modified from Acela Train Car Model
- **Power Car Model**
  - Coil spring secondary suspension
  - Radial arm primary suspension
  - Axle load 50 kips
  - Motor connection with axle
- **Coach Car Model**
  - Airbag secondary suspension
  - Radial arm primary suspension
  - Axle load 33 kips
  - No carbody tilting mechanism

**Track Model**
- One-layer track model, two 276-foot-long flexible rails
- Torsion, lateral bending and vertical bending modes
- 552 parallel rail support spring/damper connections

**ISO 2631 Ride Quality**

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<tr>
<th>Parameter</th>
<th>Value Perception</th>
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<td>Less than 0.315 m/s²</td>
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<td>1.25 m/s² to 2.5 m/s²</td>
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<td>Greater than 2 m/s²</td>
<td>Extremely uncomfortable</td>
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**FRA 213 Track Safety Standard**

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<td>Net Axle L/V Ratio</td>
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<tr>
<td>Carbody Lateral Acceleration</td>
<td>≤0.65g peak-to-peak (P2P)</td>
</tr>
<tr>
<td>Carbody Vertical Acceleration</td>
<td>≤1.0g P2P</td>
</tr>
</tbody>
</table>

**Alternative Wheel Profiles**

- **B2B Distance**
Other Performance Requirements

- European TSI
  - Equivalent Conicity <0.1
- Wear Index and Contact Stress

Simulation Matrix

<table>
<thead>
<tr>
<th>Turnouts</th>
<th>Route/Direction</th>
<th>Speed (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Design, S-C-S geometry</td>
<td>Diverging Line, Crossover</td>
<td>60, 80, 100,</td>
</tr>
<tr>
<td></td>
<td>Main Line/Facing, Trailing</td>
<td>110, 120</td>
</tr>
<tr>
<td></td>
<td>Diverging Line, Crossover</td>
<td>60, 80, 100,</td>
</tr>
<tr>
<td></td>
<td>Main Line/Facing, Trailing</td>
<td>110, 120</td>
</tr>
<tr>
<td>Double Spiral Design, S-S geometry</td>
<td>Diverging Line, Crossover</td>
<td>60, 80, 100,</td>
</tr>
<tr>
<td></td>
<td>Main Line/Facing, Trailing</td>
<td>110, 120</td>
</tr>
<tr>
<td>Pre-Steer Design, S-C-S geometry</td>
<td>Diverging Line, Crossover</td>
<td>60, 80, 100,</td>
</tr>
<tr>
<td></td>
<td>Main Line/Facing, Trailing</td>
<td>110, 120</td>
</tr>
</tbody>
</table>

Diverging Line Wheel L/V Ratios

L/V ratios on Presteer Turnout are Lowest Due to Axle Steering

Diverging Line Wheel Unload Ratios

Unload ratios on Presteer Turnout are Lowest

Diverging Line Ride Quality

Best Ride Quality on Spiral-Spiral Turnout due to Lowest CDCR

Diverging Line Wear Index

Lowest Wear Index on Presteer Turnout due to Axle Steering
Contact on Wing Rail

Hard Flange Root Contact: APTA lower contact stress by 20%

Contact on Wing Rail with 1:40 Top

Wheel tread contact stress lowered by 50% on wing rail with 1:40 top

Equivalent Conicity Definition

- Equivalent linearization by the application of Klingel formula, UIC 519
- Linear regression of the function of RRD, UIC 519
- Harmonic quasi-linearization

Equivalent Conicity Comparison

- S1002/AREMA 136 RE, highest conicity
- Negative Slope

Lateral Stability

S1002 axle hunting due to high conicity and tight W/R clearance

W/R Contact Conformality

Two-point contact on S1002/AREMA 136RE-10 and -8
### Simulation Results

**Car Running Speeds with Dynamic Performance Indices Meeting FRA 213 Track Safety Standard Limits (mph)**

<table>
<thead>
<tr>
<th>Wheels</th>
<th>Slab Track</th>
<th>Ballasted Track</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diverging</td>
<td>Main Line</td>
</tr>
<tr>
<td></td>
<td>Crossover</td>
<td>(Facing and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trailing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APTA 240</td>
<td>120</td>
<td>240</td>
</tr>
<tr>
<td>Acela</td>
<td>120</td>
<td>240</td>
</tr>
<tr>
<td>S1002</td>
<td>120</td>
<td>160</td>
</tr>
</tbody>
</table>

### Simulation Results (continued)

**Car Running Speeds with Carbody Acceleration Meeting ISO 2631 Ride Quality Criteria (a little uncomfortable perception) (mph)**

<table>
<thead>
<tr>
<th>Wheels</th>
<th>Slab Track</th>
<th>Ballasted Track</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Acela</td>
<td>100</td>
<td>240</td>
</tr>
<tr>
<td>S1002</td>
<td>100</td>
<td>140</td>
</tr>
</tbody>
</table>

### Conclusions

- 120 mph diverging operations can be accomplished with No. 43 - 49 turnouts
- Smooth alignments (tangential, spiral) are needed to improve track ride quality
  - S-S turnout provides best ride quality on diverging line due to its lowest change rate of cant deficiency (CDCR)
  - The S-S turnout provides overall better dynamic performances than the S-C-S turnout
- Switch details are important (e.g., gage, profile, etc.)
  - The presteer turnout generally provides better dynamics performances (e.g., L/V ratio, etc.) due to its axle steering capability

### Conclusions (continued)

- W/R profiles have to be compatible for optimal performances on diverging and mainline routes
  - Hunting speed of the power car implemented with standard S1002 wheelset is lower than that with APTA 240 and Acela wheels due to higher conicity and wider wheelset B2B distance
  - All running surface discontinuities should be minimized (e.g., canted switch and frog)

### Recommendations

- Change wing rail flat top to 1:40 slope to match 1:40 wheel taper for lowering tread contact stress
- Install guard rail on diverging line to prevent:
  - Hard flange root contact on wing rail and frog point
  - Excessive wear, fatigue, and most importantly, wheels picking the frog point
- Vehicle parameter optimizations, including tuning suspension system and modifying wheel profiles, are essential for improving car curving performances on turnout diverging line and stability on main line at high speeds.

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- Robert Wilson

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