OVERVIEW OF DIRECT FIXATION FASTENERS in MAJOR U.S. TRANSIT SYSTEMS

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Introduction & Overview

- Direct fixation track is also known as ballastless track
  - Non-embedded
  - Embedded
- Original use of direct fixation fasteners (DFF) date back 1920s in NYC
- Increased use of slab track design in urban areas in the second half of 20th century (e.g. MARTA, BART, WMATA)
- New fastening systems were needed to accommodate slab track design and construction
- Numerous designs were created over the years in the US and globally, all aiming to:
  - Maintain track integrity under operational loads
  - Offer noise and vibration mitigation
  - Insulate rails electrically
Pre 1970’s Direct Fixation Designs

- Non-Bonded Elastomer Designs
  - Steel Plate
  - “TIE SAVER” Pad
  - Spiked Rail

- Preformed Elastomer encased rail
  - Steel Frame container
  - Bolted rail Clamping
1970’s through 1980’s Direct Fixation Designs

• Predominantly Bonded Elastomer
  • Steel Plate fixed through fastener body anchorage points
  • Vulcanize Bonded Elastomer to form a “one piece” fastener body
  • Various bolted rail clip and spring clip designs
  • Rail Adjustment along top surface of steel plate
Mid 1980’s to Present Direct Fixation Designs

• Predominate Bonded Elastomer
  • Ductile Iron Plates fixed through bottom plate anchorage points
  • Vulcanize Bonded Elastomer to form a “one piece” fastener body
  • Predominate fixed spring clip housing
  • Rail Adjustment by moving entire fastener body
Design Evolution

1977 Design
Transit Products H12

1997 Design
LB Foster F20L0
Key Historical Milestones in the last ~40 Years

- Vulcanize Bonded Elastomer Product to form a “one piece” fastener
  - Simplified installation, improved electrical isolation leakage paths and corrosion protection
- Ductile Iron plate manufacturing provided ability to produce features
  - Bolt the fastener body through the bottom plate
  - Reduction of bolt bending stress and reduced bolt torque loss
  - Eliminate a hard vibration bridge from top plate to the mounting surface
- Introduced improved ability to cant the rail seat allowing flat plinth construction for installed system cant consistency
- Mechanical design features to provide greater lateral resilience
Typical US Agency DFF Specification Structure

• General
  ▪ Scope, references (ASTM, ASME etc.)
  ▪ Submittal requirements
    • Design
    • Qualification Testing
    • Quality Control Plan

• Products
  ▪ Allowable limits on products and materials
    • Geometry and size of features
    • Limits on fastener components (and subcomponents if applicable)
      ▪ Metal parts, elastomer parts, electrical insulation elements etc.
      • Chemistry, physical, mechanical, electrical and environmental requirements
  ▪ Qualification testing requirements

• Execution
  ▪ Packaging, loading, shipping and handling
  ▪ Production testing
Key DFF Design Parameters

- **Electrical Insulation**
  - Longer leakage path the better, but distance usually constrained due to geometry limitations
  - Typical materials used for electrically insulating the DFF: Vulcanized rubber, polyurethane, nylon etc.

- **Lateral stability**
  - Anchoring details, number of bolts, location adjustability etc.

- **Vertical dynamic stiffness**
  - Key parameter for vibration mitigation
  - Different design options to achieve the end goal as specified by the agency

- **Durability under environmental and operational conditions**
  - Repeated load testing
  - Sustained performance under exposure to various elements (oil, ozone, water, varying temperatures etc.)
### Sampling of Major US Transits - Static Spring Rate Criteria

<table>
<thead>
<tr>
<th>Agency</th>
<th>Range of Measure (pounds per fastener body)</th>
<th>Spring Rate Range (pounds / inch deflection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta (MARTA)</td>
<td>5,000 to 12,000</td>
<td>100,000 to 200,000</td>
</tr>
<tr>
<td>Denver (RTD)</td>
<td>4,000 to 12,000</td>
<td>91,800 to 124,200</td>
</tr>
<tr>
<td>Honolulu (HART)</td>
<td>4,500 to 12,000</td>
<td>94,000 to 200,000</td>
</tr>
<tr>
<td>Los Angeles (LAMTA)</td>
<td>2,000 to 10,000</td>
<td>76,000 to 114,000</td>
</tr>
<tr>
<td>Miami (MDT)</td>
<td>4,000 to 12,000</td>
<td>80,000 to 120,000</td>
</tr>
<tr>
<td></td>
<td>4,500 to 12,000</td>
<td>94,000 to 200,000</td>
</tr>
<tr>
<td>Minnesota</td>
<td>2,000 to 10,000</td>
<td>76,000 to 114,000</td>
</tr>
<tr>
<td>New York (NYCT)</td>
<td>5,000 to 10,000</td>
<td>75,000 to 120,000</td>
</tr>
<tr>
<td>Phoenix (Valley Metro)</td>
<td>4,500 to 12,000</td>
<td>90,000 to 150,000</td>
</tr>
<tr>
<td>Seattle (SST)</td>
<td>4,500 to 12,000</td>
<td>94,000 to 200,000</td>
</tr>
<tr>
<td>San Francisco (BART)</td>
<td>4,000 to 12,000</td>
<td>187,000 max</td>
</tr>
<tr>
<td>Typical High Resilient</td>
<td>2,000 to 10,000</td>
<td>40,800 to 61,200</td>
</tr>
</tbody>
</table>

Dynamic Spring Rate ~ 1.5 * Static Spring Rate
Vibration Isolation Modeling

Equivalent track mass ($m_T$) and track stiffness ($k_T$) calculation

Rail mass ($m_1$)

Rail-pad stiffness ($s_1$)

Tie/baseplate-top mass ($m_2$)

Tie-pad/baseplate-pad stiffness ($s_2$)

$$k_T = 2\sqrt{2} (EI)^{1/4} s_{eq}^{3/4}$$

$$s_{eq} = m_T w^2$$

$$w = \sqrt{\frac{m_1 s_1 + m_1 s_2 + m_2 s_1 \pm \sqrt{(m_1 s_1 + m_1 s_2 + m_2 s_1)^2 - 4 m_1 m_2 s_1 s_2}}{2 m_1 m_2}}$$

Vibration isolation model

Natural Frequency

$$f_n = \frac{1}{2\pi} \sqrt{\frac{k_T}{(m_T + m_w)}}$$

Force Transmissibility ($T_f$)

$$F_T = \frac{1}{1 - \frac{1}{(1 + in)} \left( \frac{m}{m_w} \right)^2}$$

Insertion gain

$$IG = 20 \log_{10} \left( \frac{T_f}{T_{f \text{ reference}}} \right)$$
Typical Vibration Isolation Levels

Hi-Resilient Fastener $\sim K_{dyn} = 75$ kips/in

Standard Fastener $\sim K_{dyn} = 250$ kips/in
Summary and Discussion

- Direct fixation fasteners predominantly used in the US were reviewed.
- Following challenges remain in direct fixation track design:
  - Providing softer designs with minimal allowance of increased height or width perpendicular to track.
  - Restrictions of existing plinth support areas.
  - Aging plinths leading to uneven support for direct fixation fasteners.
  - Added performance desires with demand to match existing footprints.
  - No common standards exist in the transit industry for modeling or testing vibration isolation provided by DFF as a result of wheel excitation in the frequency domain.
References

- TCRP Project D-7 Task 11, Development of Direct Fixation Fastener Specifications and Related Material, by James M. Tuten III, January 2004
THANK YOU