9. APTA PR-M-RP-009-98 Recommended Practice for New Truck Design

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Abstract: This recommended practices gives guidance for the design of new commuter and intercity rail car trucks with application speeds not exceeding 125 miles per hour (mph) (200 khp) and for the application of existing truck designs significantly different from the prior application(s) in terms of load, speed, track geometry, carbody and significant combinations of these factors.

Keywords: truck design, suspension system

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1. Overview

1.1 Scope

This recommended practices gives guidance for the design of new commuter and intercity rail car trucks with application speeds not exceeding 125 miles per hour (mph) (200 kph) and for the application of existing truck designs significantly different from the prior application(s) in terms of load, speed, track geometry, carbody and significant combinations of these factors. The truck designer should consider and satisfy all safety-related issues. The specific details of these safety-related issues should be identified in the specification by the operating authority and/or the prime contractor. In addition to safety-related issues, there are other specification issues related to passenger comfort, maintainability, reliability, quality control, interchangeability, etc. which are unique to each authority and outside the scope of this document.

The passenger rail industry phased this recommended practice into practice over the six-month period from July 1 to December 31, 1999. The recommended practice took effect January 1, 2000.

2. References

This recommended practice shall be used in conjunction with the following publications. When the following publications are superceded by an approved revision, the revision shall apply.

NUCARS, Version 2.1, (New and Untried Car Analytic Regime Simulation) Computer Program, Transportation Technology Center Inc.-a subsidiary of the Association of American Railroads (AAR) ,P.O. Box 11130, 55500 DOT Road, Pueblo, CO 81001, Attn.: Product Line Mgr.-Software, September, 1995

AWS D1.1-98 Structural Welding Code - Steel, American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126, 440 pages.

49CFR Part 213 Code of Federal Regulations, *Federal Register,* Revised as of October 1, 1995.

49CFR Part 238 (NPRM) Proposed Rules, Code of Federal Regulations, *Federal Register,* Vol. 62, No. 184, September 23, 1997

3. Definitions, abbreviations and acronyms

3.1 Definitions

3.1.1 endurance limit[1]: Represents a stress level below which a load may be repeatedly applied an indefinitely large number of times without causing failure. Unless qualified, the

[1] The Testing and Inspection of Engineering Materials, H.E. Davis, G. E. Troxell and C.T. Clement, McGraw-Hill Book Co., p. 239.

endurance limit is usually understood to be that for completely reversed bending.

3.1.2 infinite fatigue life threshold: Represents the cycle count threshold at which the endurance limit is achieved.

4. General truck functions

The function of a rail car truck is to support the vehicle, to guide the vehicle along its intended route and to transmit the tractive forces between the rail and carbody. The truck distributes the weight of the vehicle to the track through the wheels and it acts to provide the necessary steering forces to negotiate curves. Also the truck acts to attenuate the effects of track geometric irregularities on wheel load and on vibration within the car.

In order to provide the required steering forces the truck should have sufficient flexibility to align itself in curves without generating excessive lateral forces that are likely to cause the wheel to climb over the rail. The suspension design should provide sufficient control of the roll movements of the car to keep the carbody within the dynamic clearance envelope and to prevent vehicle overturning in the presence of winds and under operations at permissible speeds above and below curve balance speed.

In traversing track conforming to the governing track standards the truck should not apply forces to the rails that would cause catastrophic damage to the track, such as gauge widening and track panel shift. Under conditions where there are rapid variations in crosslevel (as permitted by the governing track geometry standards) the truck should provide sufficient wheel load equalization to permit the development of the steering forces required for curve negotiation. For applications on track with geometry not defined otherwise, the governing track standards should be those defined by the Code of Federal Regulations 49 CFR Part 213.

5. Safety-related factors

As a minimum, the safety-related factors listed in this section should be satisfied in a new truck design to ensure safe operation. For existing truck designs that are to be applied to a car design or service condition that differs significantly from the truck's previous application(s), the portions of this section that could be effected by the car design or service condition differences should be reviewed and satisfied.

5.1 Loads and stresses

The trucks and their components should be capable of bearing the static and dynamic loads imposed in service and the trucks should operate safely under all passenger load conditions from empty to crush load. The trucks and their components should be capable of enduring the shock loads imposed by normal service.

5.2 Service conditions

The trucks and associated components should operate safely under the specified conditions of operating speed, vehicle performance, environmental conditions, and track geometry conditions over the required service life of each of the respective components.

5.3 Clearances

The truck design should have sufficient stiffness and clearances to assure proper operation. This should include adequate clearances of truck-mounted components to the clearance diagram for the region of operation under all conditions of vehicle loading and carbody lean and roll conditions and for any component wear conditions from new to fully worn. The truck suspension should provide adequate stiffness to the carbody for the various degrees of freedom to assure that the vehicle carbody stays within the clearance diagram for all normal operating conditions and certain abnormal conditions which could include a reasonable combination of failed suspension elements. There should be ample clearances between members of the truck and carbody mounted equipment to allow unrestrained truck swivel (yaw), roll and pitch motions for normal operation. Mechanical stops should be provided to limit travel beyond the limits which would be injurious to the equipment. Also the truck should be designed to have adequate clearances between its various components to assure proper operation.

5.4 Track worthiness

The truck should be designed to keep the vehicle on the track under all normal operating conditions. This will be discussed further in Section 6.2.

5.5 Locking means

Suitable locking means should be provided to secure the truck to the carbody, the truck frame to the bolster, and the wheelsets to the truck frame. Please refer to the APTA PR-CS-S-034 99 Rev. 1 Standard for the Design and Construction of Passenger Railroad Rolling Stock

Each component of a truck (which includes axles, wheels, bearings, the truck mounted-brake system, suspension system components, and any other components attached to the truck by design) shall remain attached to the truck when a force equivalent to 2g acting on the mass of the component is exerted in any direction on that component.[2]

5.6 Fail-safe design of critical components

The vehicle suspension system and the carbody tilting system, if used, should be designed with suitable backup suspension or safety stop means to reduce the likelihood of a catastrophic vehicle failure, derailment, collision or extension beyond the track clearance envelope in the event of a failure in the normal suspension and/or tilting element(s) or system(s).

Backup safety means should be provided for the traction motors and for the gear units to prevent these components from causing a derailment as a result of a failure of the normal traction motor or gear unit suspension devices.

5.7 Air reservoir structural integrity

Truck mounted air reservoirs should be safe for the pressure to which they may be subjected in the event of a failure of supply-regulating means.

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2 49CFR Part 238.419(b) Proposed Rules "Truck-to-car-body and truck component attachment." Federal Register, Vol. 62, No. 184, September 23, 1997, p. 49817.

5.8 Shop safety

The truck and its components should be designed with consideration for the personnel safety during shop maintenance activities. Sharp edges and pinch points should be avoided where practical. Lifting and jacking locations of adequate structural strength should be provided for normal shop assembly and disassembly activities.

6. Design analysis

Design analysis should be conducted to demonstrate that new commuter and intercity rail car trucks will operate safely for the required service life under the environmental, operating and physical conditions as specified by the vehicle buyer/operating railroad. The design analysis should include structural design analysis and dynamic analysis.

6.1 Structural design analysis

All truck structural components should have the necessary strength with adequate safety factors to withstand the maximum stresses imposed in service including static and fatigue loads, vibration, track shocks, motor and braking loads and anticipated combinations of these forces. Welded steel truck structures should conform to AWS D1.1 or equivalent for fatigue life design.

Stress analysis should include the calculated stresses, allowable stresses and safety margins for all truck structural components under all anticipated loading conditions and load combinations. The stress analysis may consist of finite element analysis (FEA) supplemented as necessary by conventional calculations.

6.2 Dynamic analysis

A dynamic analysis is recommended for new or unproven truck designs to evaluate track worthiness, derailment potential and ability to operate within the clearance diagram. This analysis should use a recognized rail vehicle-track dynamics computer program such as AAR NUCARS. As a minimum, the parameters evaluated should include critical hunting stability, wheel load equalization, lateral wheel/rail forces, and lateral/vertical force ratios. Both the new and worn truck conditions should be evaluated.

As a further indication that the suspension stiffness' have been properly designed, a dynamic clearance envelope study of the completed car should be conducted to ascertain that wayside clearance limits are not exceeded by any portion of the car under any combination of load and operating conditions, new or worn condition, and suspension component failure.

6.3 Track worthiness analysis

The items listed in this section should be verified by calculations using a recognized rail vehicle-track dynamics computer program such as AAR NUCARS.

6.3.1 Wheel unloading

Under any operating condition permitted by the vehicle buyer over track within the limits of the governing track geometry standards, the vertical load on any wheel of the truck should not be less than 10% of the vertical load that would exist on that wheel when the vehicle is stationary on perfectly level tangent track (the static vertical wheel load) for a distance traveled along the track of 5 feet (1.5m) or more.

6.3.2 Vehicle overturning

In negotiating a curve with uniform super-elevation in steady-state conditions, no vertical wheel load should be less than 60% of its static value on level tangent track. Compliance should be demonstrated for two extreme conditions:

Static lean on maximum super-elevation.

Static lean on negative super-elevation corresponding to roll deflection at the maximum allowable speed in excess of balance speed.

6.3.3 Wheel climb

In negotiation of any curve with any track irregularity permitted by the governing track standards, the ratio of lateral force (L) to vertical force (V) on any wheel should not exceed the ratio given by Equation 1. (with a coefficient of friction of 0.5) for a distance of 5 feet (1.5m) or more.

$L/V = [\tan\delta - \mu]/ [1+\mu \tan \delta]=(1)$

where δ = wheel rail contact angle

and μ = coefficient of friction; a value of 0.5 should be used

6.3.4 Track panel shift

The total lateral force applied by any axle of the truck to the track should not exceed 50% of that axle's static vertical load for a distance traversed along the track of 5 feet (1.5 m) or more.

6.3.5 Gauge widening forces

The total dynamic lateral force exerted by a truck on a single rail should not exceed 60% of the vertical force exerted by that truck on that rail for a distance of 5 feet (1.5m) or more.

6.3.6 Truck hunting

New commuter and intercity rail car trucks should exhibit freedom from hunting oscillations at all speeds from zero to 5 mph (8 km/h) above the maximum intended operating speed of the vehicle under worst-case conditions including component wear. A single definition of worst-case operating environment is not possible due to the wide variation in conditions from one railroad to the next. Therefore it is the responsibility of the vehicle buyer/operating railroad to provide the definition of worst-case operating environment conditions to the vehicle/truck supplier for use in these analyses. For the purpose of this analysis, hunting is defined to be truck frame lateral oscillations exceeding 0.8 g peak-to-peak for six or more consecutive oscillations.[3]

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[3] 49CFR Part 238.5 Proposed Rules "Definitions...Hunting Oscillations", Federal Register, Vol. 62, No. 184, Sept. 23, 1997, p 49793,

7. Qualification tests

Qualification tests of all new or unproven truck designs should be performed on a representative specimen to demonstrate conformance to specification safety requirements. For trucks similar in design or application to previous experience, the Vehicle Buyer may elect to waive any or all portions of these Qualification Tests if design adequacy can be proven by engineering analysis by previously completed equivalent testing and/or by successful service of the truck.

7.1 Structural integrity

7.1.1 Truck static test

This test is to verify that maximum allowable static stresses are not exceeded. The truck should be tested either as individual load bearing components or as an assembly. Whichever method is chosen, provision should be made to apply all input loads described below and to restrain these input loads in a manner that is functionally equivalent to the reactive forces which occur in service. Loads should enter the truck components at the normal application points and should be combined in each case as to produce the most severe load combinations that are anticipated in normal service.

Input loads should include static and dynamic augment vertical, lateral, longitudinal, roll, braking and motor and gear unit (if applicable).

Strain measurement techniques should be used on the truck structure at maximum stress points as agreed to by the truck supplier and the buyer. The locations of maximum stress points should be determined by design analysis and/or by a preliminary static test to determine location and orientation of stresses using brittle lacquer or equal.

7.1.2 Truck fatigue test

To demonstrate that the truck has adequate fatigue strength under dynamic loading, the truck frame and bolster should be subjected to combined normal loading cycles equal in number to the infinite fatigue life thresholds of the material and fabrication details used in truck construction. The truck may contain its internal elastomeric cushioning and springs or substitute blocking.

For the types of load applications where the extreme excursions are expected to occur at a substantially lower rate, such as a full load reversal due to change in direction of travel or due to an emergency brake application, the truck fatigue test duty cycle should be adjusted to test at these extreme load excursion levels only for the number of these extreme load cycles that can realistically be expected to occur during the specified design life of the truck. The number of extreme load cycles to be tested is to be agreed upon by the vehicle buyer/railroad and the truck supplier.

Typically the infinite fatigue life threshold for cast steel structures is considered to be two million cycles.

Welded steel structures are not considered to have attained full endurance limit until the infinite fatigue life threshold for the most severe non-redundant fatigue strength weld detail is reached.

This welded structure threshold can be as high as 14 million cycles as defined by the *American Welding Society Structural Welding Code D1.1*.[4]

Fatigue loads should include as a minimum vertical static plus vertical dynamic augment, lateral, longitudinal, roll, braking and motor and gear unit (if applicable). The phasing of combined loads should be arranged to produce both maximum and minimum stress levels at critical locations for reasonably anticipated service load combinations.

During and at the conclusion of the fatigue test, the truck should be inspected by industry-recognized methods to detect evidence of crack initiation or progression. Precise definition of a "failure" should be agreed upon in advance of truck testing.

7.1.3 Truck mounted reservoirs

All pressurized fluid reservoirs that are part of the truck assembly should be subjected to a hydrostatic pressure test at 1.5 times maximum working pressure (in accordance with ASME Boiler and Pressure Vessel Code).

7.2 Wheel load equalization test

To verify the equalization provided by the truck design, a completed empty (worst load case) vehicle should be positioned on level track and the following tests shall be conducted:

When any one wheel is raised to the amount specified by the vehicle buyer's specification, no other wheel tread should lose contact with the running surface of the rails.

When any one wheel is raised by a second amount specified by the vehicle buyer, the percent change in wheel load allowed by the vehicle buyer's specification should not be exceeded.

7.3 Lean test

To verify the vehicle stability provided by the truck design, a completed car with simulated crush load should be elevated at one rail by the specification prescribed amount to simulate super-elevation. Lateral displacements and roll angle of the carbody should be measured and compared for compliance to the buyer's specification vehicle dynamic outline limits.

7.4 Curve clearance test

Truck clearances should be confirmed by moving a train over a curve or cross over duplicating the most restrictive track work specified. Clearances should be checked internal to the truck and between the truck and other items including truck mounted equipment, carbody and carbody mounted equipment. Alternatively, the clearance may be checked using a transfer table to duplicate the most restrictive track work.

7.5 Service tests

For special circumstances such as radically new unproven truck concepts, anticipated operating

[4] For references in Italics, see Section 2.

speeds substantially higher than previously experienced by the truck design, or track conditions substantially different from previous experience with a given truck design, service testing of the completed equipment on representative rail line may be required to validate the safety aspects of the truck dynamic analyses. Such service testing is normally not mandated for substantially service proven trucks operating in similar speed, load and track conditions as previous applications.

When new passenger vehicle trucks are intended for service speeds in excess of 110 mph (177 km/h), these trucks, installed on the corresponding vehicles, should demonstrate stable operation during pre-revenue service qualification tests at all speeds up to 5 mph (8 km/h) in excess of the maximum intended operating speed, under worst-case conditions of component wear over the worst-case track conditions (for the corresponding speeds) as determined by the operating railroad.