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Measurement of Revenue Service Coupler Force Environment – Cushioning Units on Bi-level Autorack Cars

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Summary

Railroads continue to experience coupler related failures in standard revenue service. Particularly noteworthy recently have been failures on cars fitted with end-of-car (EOC) cushioning units. As a result, the level of peak coupler draft force created within trains composed of large numbers of cars equipped with 10-inch displacement cushioning units is being studied.

The availability of revenue service dynamic coupler load data is generally limited for cars with EOC cushioning units. Consequently, a test program was designed to record a large quantity of dynamic load data to make reasonably accurate estimates of the effects of those forces on car structural integrity. Transducers were mounted on a loaded bi-level autorack car with a 141,000-pound gross rail load. The test car was then inserted into revenue service trains from October 2013 to September 2014 and allowed to collect over 20,000 miles of coupler force, coupler displacement, and carbody acceleration data. Test routes were on revenue service track in the western United States and southeastern Canada.

Buff and draft coupler force data was rain-flow cycle counted and summarized in the form of maximum and minimum force histograms. Comparisons of load environment severity were based on calculated coupler knuckle fatigue damage due to draft load cycles. Examination of the data revealed the following key observations:

- Maximum train action related draft force was 612,600 pounds. This force exceeds the knuckle permanent set load of 400,000 pounds defined in AAR M-211 (*Manual of Standards and Recommended Practices*) and is over 94 percent of the knuckle minimum ultimate load specification of 650,000 pounds. Draft forces over 300,000 pounds occurred rarely but peak forces as high as 200,000–250,000 pounds were common throughout the duration of the test.
- Maximum train action related buff force was 234,100 pounds. Peak buff forces greater than ~225,000 pounds were rare, but forces in the 150,000 to 180,000 pound range occurred at a higher rate.
- The maximum draft load occurred with the test car in the rear third of the train coupled among 55 other loaded autorack cars equipped with cushioning units. The maximum buff load occurred when the test car was positioned in the rear third of a 76-car general manifest service train.
- A significant increase in calculated knuckle damage, when compared with damage calculated using previously recorded coupler force data for cars with standard draft gear, was observed when the test car was positioned in the middle to rear third of the train consist. The cars coupled to the test car were not always equipped with cushioning units.



INTRODUCTION

Railroads continue to experience coupler related failures in standard revenue service. Particularly noteworthy have been recent failures on cars fitted with EOC cushioning draft gear. High dynamic coupler loads and accelerated fatigue damage could be some of the most significant operational problems resulting from the use of longer trains containing a large number of cars equipped with EOC cushioning units.

In 2012 and 2013, almost 22,000 miles of revenue service coupler force data was recorded using a loaded boxcar equipped with standard 15-inch travel cushion units. The test results indicated the use of 15-inch stroke EOC cushioning units on heavy axle load cars could have an adverse effect on car structure and component fatigue life primarily when the cushioning unit car is positioned in the last 25–30 percent of the train.¹

The primary objective of the research reported here was to collect a relatively large quantity of similar revenue service coupler force data for a loaded bi-level autorack car equipped with 10-inch stroke EOC cushioning units and to relate the severity of that data to similar data recorded previously on cars with standard draft gear and the data recorded using the boxcar equipped with 15-inch stroke cushioning units.¹

PROCEDURE

The autorack car selected for this test was rated at 175,600 pounds GRL and equipped with standard 10-inch stroke, EOC cushioning units (Ref. AAR M-921D). The car was loaded with scrap vehicles to bring the actual measured test weight to 141,200 pounds. Transducers were installed on the car to measure longitudinal coupler force and displacement, carbody acceleration, and center sill stress. The set of transducers was an instrumented and calibrated SBE69CE coupler on the A-end of the car, a set of triaxial accelerometers (vertical, lateral, and longitudinal) mounted on the center sill on each end of the car, and one strain gage rosette mounted on the center sill inboard of the buff stops to measure coupler force induced strain. Two string potentiometers were used to measure coupler displacement.

Car speed and location were recorded using GPS information. Data from the transducer set was recorded on an unmanned data acquisition system. Table 1 is a summary of the routes and distances traveled.

Table 1. Test Routes

Routes	Mileage
Loaded Autorack Trains, Western United States	5,800
Empty Autorack Trains, Western United States	2,540
General Service Manifest Trains, Western United States	7,000
Trains with Large Number of Loaded Autorack Cars, Canada	2,640
Trains with Large Number of Empty Autorack Cars, Canada	1,970
General Service Manifest Trains, Canada	340

RESULTS

The maximum train action related coupler forces observed during this test were 612,600 pounds draft and 234,100 pounds buff. Forces near these levels were rare, however. There were also a relatively large number of train action related draft force cycles recorded with peak values over 250,000 pounds. Observation of large peak forces, however, does not provide an adequate evaluation of relative load severity. A large number of cycles with peak draft force values below 225,000 to 250,000 pounds could also have a significant effect on component structural damage, especially if some components such as couplers have surface defects in high stress locations. Therefore, for this study, fatigue damage accumulated for the knuckle pulling face was the primary criteria used to evaluate relative severity of coupler force. This method specifically emphasizes the importance of draft forces. A relationship between draft force and stress in the knuckle pulling face had been determined from significant finite element modeling completed during previous research projects.^{2,3} Fatigue damage was then estimated using fatigue life prediction software. The software performed a cumulative damage strain life analysis by calculating fatigue damage for each cycle contained in the stress-strain environment. Damage calculations were completed using the estimated strain life fatigue properties of an AAR Grade E cast surface with defects as well as a surface with no defects in an effort to more accurately assess the effects of the full spectrum of coupler forces. To compare damage calculations estimated over different test distances, all damage numbers were normalized to damage per mile by dividing calculated damage by test distance.

Fatigue damage calculated using the data recorded during this test was compared with that calculated for a force spectrum recorded previously for a car equipped with standard draft gear. The spectrum chosen for comparison was the “Loaded 100-ton Hopper Car Severe Environment” contained in Chapter 7, Section C-Part II of the *AAR Manual of Standards and Recommended Practices*. Therefore, the damage per mile value calculated for this environment spectrum was arbitrarily set to 1.0 and all other spectrums were related to it for severity. To provide a better understanding of how relative ratings relate to life until crack initiation on the knuckle face, consider that the rating of 1.0 would be equivalent to a life of about 1.6- to 9.1-million miles depending on the surface condition of the knuckle. Table 2 shows the relative damage calculated using two other load spectrums. The first spectrum was that measured in revenue service for a heavy axle load boxcar equipped with 15-inch displacement cushioning units, and the other spectrum is that specified in AAR Standard M-216, Knuckles, Types E and F – Fatigue Test.¹

For the data collected during this test, knuckle damage per mile was calculated over relatively long durations and for individual trips. Table 3 shows damage estimation results calculated over several thousand miles for test segments segregated by route, train type, or location. Table 4 shows

similar damage estimations during individual trips in the United States, and Table 5 shows damage per mile for individual trips in Canada. Table 5 data was recorded during 17 trips over the same Canadian route. This route contains a segment of undulating track that can result in large train action produced coupler forces. Analysis of data over individual trips was an effort to demonstrate some of the effects of train consist details and locomotive operation on coupler force and knuckle fatigue damage severity. Table 6 shows additional details of the train consists existing when the most severe coupler draft forces and knuckle fatigue damage was recorded.

Table 2. Calculated Knuckle Fatigue in Terms of Damage per Mile for Existing Load Spectrums

Relative Knuckle Fatigue – Damage Per Mile	
Load Spectrum	Relative Damage
AAR Hopper Car “Severe”	1.00
Cushioning Unit Equipped Boxcar	1.00
AAR M-216 Test Spectrum	1.22

Table 3. Calculated Knuckle Fatigue in Terms of Damage per Mile, Many Miles, Multiple Routes

Type of Service	Data Miles	Relative Damage
Mixed Manifest and Autorack Trains, Western U.S.	15,340	1.63
Trains with only Loaded Autorack Cars, Western U.S.	5,800	1.32
Trains with only Empty Autorack Cars, Western U.S.	2,540	0.59
General Service Manifest Trains, Western United States	7,000	2.07
Mixed Manifest and Loaded Autorack Trains, Canada	2,640	11.94
Mixed Manifest and Empty Autorack Trains, Canada	1,970	4.36

Table 4. Calculated Knuckle Fatigue in Terms of Damage per Mile, Single Trips & Routes – United States

Train Type	No. of Cars in Train	Position of Test Car From Head End	Data Miles	Relative Damage
Manifest	106	47	396	7.39
Manifest	71	62	329	6.57
Manifest	76	58	756	4.43
Manifest	161	114	220	3.93
Loaded Autorack Cars	70	60	618	3.01
Loaded Autorack Cars	77	56	1,720	2.71
Loaded Autorack Cars	51	5	967	0.92
Loaded Autorack Cars	70	8	1,312	0.43
Empty Autorack Cars	70	53	1,861	0.68

Table 5. Calculated Knuckle Fatigue in Terms of Damage per Mile, Single Train Types — Canada

Autorack Block	No. of Cars in Train	Position of Test Car From Head End	Data Miles	Relative Damage
55 Loaded	132	129	334	61.47
68 Loaded	137	122	325	11.09
51 Loaded	125	76	333	8.99
32 Empty	98	72	322	7.31
61 Loaded	145	115	324	5.81
24 Empty, 3 Loaded	116	110	326	5.51
68 Empty	106	106	333	4.57
27 Loaded	133	133	331	3.63
19 Loaded	150	137	334	3.62
26 Empty, 5 Loaded	38	8	340	3.44

Table 6. Consist Details — Trips with Highest Knuckle Fatigue Damage per Mile

Date	Comments	Relative Damage
Aug. 21–22	Distributed Power between cars 74 & 75. Cars 78 to 132 loaded autorack cars. Test car 128 of 132	61.47
Aug. 14–15	Distributed Power between cars 77 & 78. Cars 70 to 137 loaded autorack cars. Test car 122 of 137	11.09
Aug. 30–31	Distributed Power between cars 62 & 63. Cars 75 to 125 loaded autorack cars. Test car 76 of 125	8.99
Dec. 18–19	Test car 47 of 106. Cars 54, 51, 50, & 45 loaded cushioning unit (EOC) equipped. Cars 48 & 49 empty EOC equipped. Trailing cars – 8 loaded EOC, 32 empty standard draft gear, 14 loaded standard gear	7.39
Aug. 20	Cars 66 to 98 empty autorack cars. Test car 72 of 98	7.31
Jan. 22–24	Test car 62 of 71. Cars 53 & 54 loaded cushioning unit (EOC) equipped. Cars 57, 59 & 60 empty EOC equipped. Remaining cars standard draft gear equipped	6.57
Aug. 18–19	Distributed Power between cars 68 & 69. Cars 85 to 145 loaded autorack cars. Test car 115 of 145	5.81
Aug. 29	Cars 90 to 109, 111, 113, 114, & 116 empty autorack cars. Cars 112 & 115 loaded autorack cars. Test car 110 of 116	5.51
Sept. 4–5	Test car at end of 106 car train. Cars 38 to 105 empty autorack cars	4.57

The summary data in these tables allow several key observations. Over many miles of mixed freight service through a wide variety of terrain, the coupler load environment for the test car equipped with 10-inch cushioning units does not appear to be significantly more severe than that of a car equipped with standard draft gear.

However, when damage was estimated over shorter distances, there were combinations of terrain, locomotive operation, and consist makeup that resulted in significantly increased knuckle damage per mile values (Tables 4–6). The high damage values resulted from multiple draft force cycles with peaks in the range of 220,000 to over 500,000 pounds. As with the revenue service data recorded in 2012 and 2013, a general, recognizable trend was that draft forces and knuckle damage was especially elevated when the test car was coupled among other cushioning unit equipped cars in the middle to rear third of the train.

Of particular interest is coupler data recorded on the Canadian routes when distributed power was located near the half-way point of the train consist. With the test car aft of the distributed power locomotive and located in the rear half of a block of 50 to 70 loaded autorack cars, high level draft coupler forces were recorded. Not only did peak draft forces occasionally exceed 500,000 pounds, but there were numerous cycles with peak values in the 250,000 to 300,000 pound range. The result was a significant increase in knuckle damage, as Tables 5 and 6 show.

A likely significant contributor to the creation of high draft forces on a section of the Canadian route was the combination of undulating terrain and locomotive operation. It was clear that the use of distributed power did not result in reduced draft coupler forces in cars aft of the remote locomotive. For example, Figure 1 shows longitudinal coupler force (draft force negative) as the test car traveled over a section of undulating terrain during the August 14 to 15 trip (Table 6). Figure 2 shows the throttle position and the dynamic brake settings for the remote locomotive during the same approximate time period.

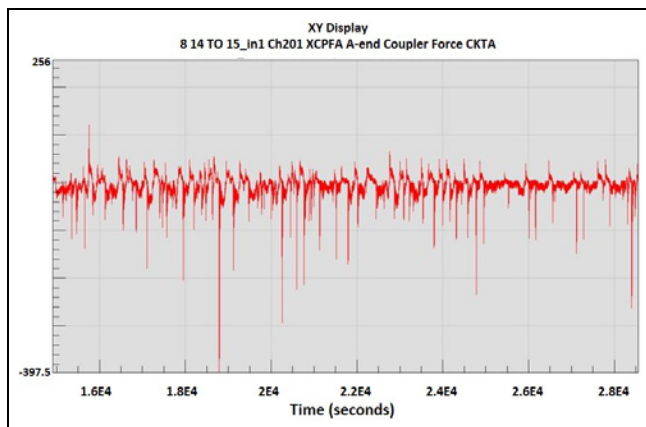


Figure 1. Longitudinal Coupler Force

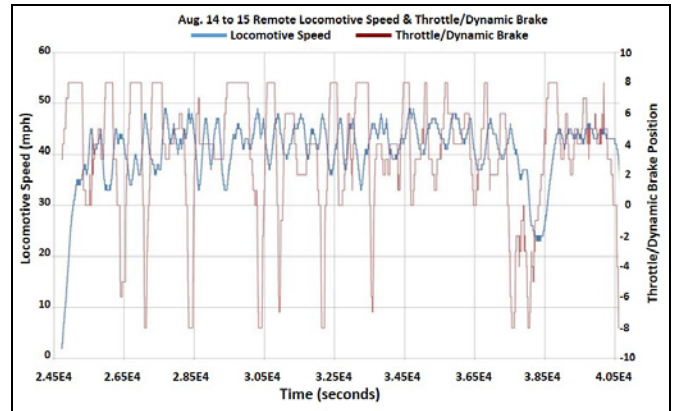


Figure 2. Remote Locomotive Dynamic Brake and Throttle

CONCLUSIONS

The revenue service data recorded and processed during this test indicates the use of 10-inch displacement EOC cushioning units on autorack cars could have an adverse effect on car structure and component fatigue life, as well as protection of the payload, primarily when such cars are positioned in the last 25–30 percent of the train and coupled among other loaded cushioning unit cars. Use of distributed power in longer trains does not reduce the severity of the draft forces in cars trailing the distributed power unit if that locomotive is not operated in a way that could minimize draft forces in those trailing cars. If acceptable life for a car component such as a knuckle was 2.4-million miles (80,000 miles per year for 30 years) for 68 percent of a population, the lives corresponding to many of the relative damage numbers shown in Tables 4 to 6 would fall well short of that goal. A relative damage number of about 4.0 would correspond to a knuckle fatigue life for 68 percent of a population of ~400,000- to 2.4-million miles depending on the surface conditions of the knuckle.

The objective of an extensive matrix of simulations will be to further study the effects of key variables such as train length and the position of blocks of autorack cars within the train in an effort to reduce dynamic coupler buff and draft forces during travel over undulating terrain.

REFERENCES

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