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Measurement of Revenue Service Coupler Force Environment – Cushioning Units on 286,000-pound Gross Rail Load Box Car

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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. Concern has grown that use of long travel cushioning units may result in larger peak draft forces than with standard travel drawgear during normal train operations. The draft force levels may be especially high when several cushioning unit cars are coupled together in a train.

The availability of revenue service dynamic coupler load data is generally limited for cars with EOC cushioning units. Consequently, a 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 stability and structural integrity. Transducers were mounted on a box car rated at 286,000-pound gross rail load. The test car was then inserted in revenue service trains from September 2012 to February 2013 and allowed to collect almost 22,000 miles of coupler force, coupler displacement, and carbody acceleration data. Test routes were on the track of two major railways in the United States and Canada.

Buff and draft coupler force data was rainflow 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 326,500 pounds. Draft forces as high as 225,000–275,000 pounds were also relatively common throughout the duration of the test.
- Maximum train action related buff force was 320,400 pounds. However, peak buff forces greater than ~225,000 pounds were relatively rare.
- During periods of significant train action, cushion unit displacement was recorded over a range of ~0.8-inch extension to 2.0 inches compression.
- Both the maximum buff and maximum draft loads occurred when the test car was positioned in the rear third of the train, coupled to other loaded cars equipped with EOC cushioning units.
- The most significant increase in relative, calculated knuckle damage, when compared with damage calculated using previously recorded coupler force data, was observed when the test car was positioned in the rear third of the train consist, coupled among other loaded cars 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. There is an immediate concern that 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.

The availability of revenue service dynamic coupler load data from cars equipped with EOC cushioning units has been limited. As a result, there was a need for a program designed to aid in the understanding of the magnitude of the full spectrum of the revenue service load environment for cars equipped with cushioning units.

The primary objective of this research was to collect a relatively large quantity of revenue service coupler force data for a 286,000-pound gross rail load (GRL) freight car equipped with 15-inch stroke EOC cushioning units and to relate the severity of that data to similar data recorded previously on cars with standard draft gear.

PROCEDURE

The car selected for this test was a 50-foot box car (40-foot 10-inch truck centers), BNSF726560, rated at 286,000 pounds GRL and equipped with Keystone 15G 11865, 15-inch stroke, EOC cushioning units (Ref. AAR M-921B). The car was loaded with water-filled drums and steel ingots to bring the actual measured test weight to 280,425 pounds. See Figure 1.



Figure 1. BNSF726560 Test Car

Transducers were installed on the car to measure longitudinal coupler force and displacement, carbody acceleration, side frame dynamic vertical and lateral forces, and center sill stress. The set of transducers was as follows: instrumented and calibrated SBE67CE coupler on the A-end of the car, set of triaxial accelerometers (vertical, lateral, and longitudinal) mounted on the center sill on each end of the car,

strain gages mounted on one side frame to measure dynamic, vertical and lateral forces on the side frame, and one strain gage rosette mounted on the center sill inboard of the buff stops to measure coupler force induced strain. One laser unit and one string potentiometer were used to measure coupler displacement.

Car speed and location were recorded using GPS information. Data from the transducer set was recorded on a Transportation Technology Center, Inc. (TTCI) unmanned data acquisition system (UDAC). The system was powered by a set of gel cell 12 volt batteries. Adequate charge was maintained in the battery set through the use of a generator integrated into one of the wheel bearings combined with a set of solar cells mounted on top of the car.

Data was recorded continually while the car was in motion or when significant forces were applied. Time domain and rainflow cycle counted histogram data was recorded during the test duration and stored on the UDAC system hard drive. Coupler forces, center sill stress, and side frame force data was cycle counted every 12 hours during the test. Histograms of this data were transmitted to TTCI personnel via e-mail twice daily. The full set of time domain files was always retained on the hard drive and only downloaded from the system when TTCI personnel visited the car.

Almost 22,000 miles of data was recorded while the car traveled over various routes in the United States and Canada. Train routing and train consist information was also recorded for each segment of the test. Table 1 is a summary of the routes and distances traveled.

Table 1. Test Routes

Railroad	Routes	Mileage
U.S. Railroad	General service, Colorado to Alabama and California to Illinois	4,580
U.S. Railroad	General Service, Illinois to Washington, Washington to Colorado	2,785
U. S. Railroad	Unit Coil Train, Alabama to California	1,870
Canadian Railroad	General Service, in Ontario and Quebec	11,985

At different times during the test, the car was equipped with three versions of 15-inch travel cushioning units. At the beginning of testing, the car was equipped with standard used units. After ~12,600 miles of testing, the used units were replaced by new standard units, and during the later stages of testing the car was equipped with new active draft units. Table 2 shows details of the distance accumulated by each cushioning unit.

Table 2. Cushioning Unit Usage During Test

Cushioning Unit	Routes	Distance (miles)
Standard Used	U. S. & Canadian Routes	12,241
Standard New	Canadian Routes	1,926
Active Draft	U. S. & Canadian routes	6,990

RESULTS

The maximum train action related coupler forces observed during this test were relatively high at 326,500 pounds draft and 320,400 pounds buff. Forces near these levels were rare, however. There were also a relatively large number of train action peak draft forces between 225,000 and 275,000 pounds. Observation of large peak forces, however, does not provide an adequate evaluation of relative load severity. A large number of cycles with peak values below 225,000 pounds draft forces 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.^{1,2} Fatigue damage was then estimated using the fatigue life prediction software, nCode Glyphworks. 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” formerly 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. In order to provide a better understanding of how relative ratings relate to life until crack initiation on the a knuckle face, consider that the rating of 1.0 would be equivalent to a life of ~1.6–9.1 million miles, depending on the surface condition of the knuckle. Table 3 also shows the relative damage calculated using the load spectrum specified in AAR Standard M-216, Knuckles, Types E and F – Fatigue Test. Note that this spectrum is ~20 percent more severe than that of the “Loaded 100-ton Hopper Car Severe Environment.”

Table 3. Calculated Knuckle Fatigue in Terms of Damage per Mile for Existing AAR Load Spectrums

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

For the data collected during this test, knuckle damage per mile was calculated over relatively long durations as well as for individual trips. Damage calculations were also segregated according to variations in cushioning unit usage. Tables 4–7 show this approach. Table 4 shows damage estimation results calculated over several thousand miles for test segments segregated by cushioning unit type (used versus new 15-inch stroke standard units) and railroad. Damage per mile is also calculated for only the 2,430 miles of the unit coil train trip between Alabama and California. Table 5 shows similar damage information when the test car was equipped with 15-inch stroke active draft units.

Table 4. Calculated Knuckle Fatigue in Terms of Damage per Mile, Standard Cushioning Units

Cushioning Units	Type of Service	Test Miles	Relative Damage
Standard Used 15-inch EOC	General Freight and Unit Train U. S. and Canada	12,241	0.44
Standard Used 15-inch EOC	Unit Coil Train*	2,430	1.33
Standard Used 15-inch EOC	General Freight Canada Only	5,854	0.86
Standard New 15-inch EOC	General Freight Canada Only	1,926	3.97
Standard 15-inch EOC New and Used	General Freight and Unit Train U.S. and Canada	14,790	1.00
Standard 15-inch EOC New and Used	General Freight Canada Only	7,780	1.56

*Test car position 37 out of 46 cars, 1 head end and 2 trailing locomotives

Table 5. Calculated Knuckle Fatigue in Terms of Damage per Mile, Active Draft Cushioning Units

Cushioning Units	Type of Service	Test Miles	Relative Damage
New 15-inch Active Draft	General Freight Canada Only	4,205	0.54
New 15-inch Active Draft	General Freight U.S. Only	2,785	0.84

Tables 6 and 7 summarize relative damage for individual trips on Canadian track between Ontario and Quebec. A total of 35 trips were completed on a relatively short, undulating section of Canadian track. Analysis of data over individual trips was an effort to demonstrate some of the effects of train consist details on coupler force and knuckle fatigue damage severity.

Table 6. Knuckle Fatigue for Individual Trips in Canadian Service, Test Car in Rear Third of Train among Loaded EOC Cars

Date	Cushioning Units	Test Miles	Relative Damage
Nov. 18	Standard Used 15-inch EOC	346	7.03
Nov. 25	Standard Used 15-inch EOC	189	8.29
Nov. 24*	Standard Used 15-inch EOC	177	10.3
Dec. 1–2	Standard New 15-inch EOC	350	3.95
Dec. 4–5	Standard New 15-inch EOC	139	5.59
Dec. 19	New 15-inch Active Draft	353	5.36

Table 7. Knuckle Fatigue for Individual Trips in Canadian Service, Test Car in Center or Rear Third of Train among Loaded Cars with Standard Draft Gear or Empty EOC Cars

Date	Cushioning Units	Test Miles	Relative Damage
Nov. 26	Standard Used 15-inch EOC	350	0.48
Dec. 2–3	Standard New 15-inch EOC	350	0.59
Dec. 11	Standard New 15-inch EOC	360	2.26
Dec. 10	Standard New 15-inch EOC	350	2.51
Dec. 21	New 15-inch Active Draft	350	0.79
Dec. 23	New 15-inch Active Draft	350	2.65
Jan. 6	New 15-inch Active Draft	350	1.91

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 15-inch cushioning units does not appear to be more severe than that of a car equipped with standard draft gear.
- However, placement of the test car in the rear third of a train consist among other loaded cushioning unit cars traveling over undulating terrain appeared to produce a significant increase in load environment severity. The variable of locomotive throttle control has not yet been examined, but the fact that for each trip shown in Table 6 test car placement and train consist details around the test car are similar is strong evidence that these variables are significant.
- The test data does not give a clear indication that the active draft cushioning units provided a significant decrease in load environment when compared to standard units. This was especially true when the car was exposed to a more severe environment such as that represented in Table 6. Results could be different, however, if a group of active draft cushion unit cars are coupled together.
- The data recorded during this test did not provide any real correlation between high coupler forces and variations of lateral or vertical force on the instrumented side frame.

The route between Ontario and Quebec featured sections of undulating terrain, which most likely generated the significant buff and draft train action. This train action may have been a contributing factor to the higher coupler forces and damage observed for the Canadian portion of the testing.

There were also some key observations related to coupler displacement during segments of significant train action on the Canadian route:

- During particularly active segments, coupler force cycled from ~90,000–100,000 pounds buff force to 200,000–275,000 pounds draft force.
- This coupler force variation resulted in total cushioning unit displacement of 2.8–3.0 inches, approximately 0.8-inch draft to 2.0 inches buff.
- During these events, coupler velocity in draft reached peaks of 20–27 inches per second over a displacement of ~2.5 inches. The average velocity over the entire range of displacement, however, was closer to 10–15 inches per second. In buff peak displacement, velocity reached peaks of 11 to 18 inches per second over a displacement of ~1.4 inches. The average velocity over the total range of displacement was closer to 4 to 13 inches per second.

CONCLUSIONS

The revenue service data recorded and processed during this test indicates the use of 15-inch displacement EOC cushioning units 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 and coupled among other loaded cushioning unit 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 the relative damage numbers shown in Table 6 would fall well short of that goal. A relative damage number of ~4.0 would correspond to a knuckle fatigue life for 68 percent of a population of ~400,000–2.4 million miles, depending on the surface conditions of the knuckle.

Even though a car is not likely to be exposed to an environment this severe during a large portion of its service life, it is useful to recognize that for EOC cushioning unit equipped cars, the combination of car placement, train makeup, terrain, and train operation could cause fatigue damage accumulate at substantially accelerated rates.

REFERENCES

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