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Measurement of Coupler Load Spectrum Heavy Haul Coal Hopper Car Service

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Summary

Transportation Technology Center, Inc. recently completed a program to measure the dynamic longitudinal coupler forces imposed on one 286,000-pound gross rail load coal hopper car as it traveled over 8,700 miles in typical revenue service operations.

Strain gage transducers were installed on one coupler of a 4,020-cubic foot capacity aluminum coal hopper car. The transducers were installed in such a way that the bridge circuit output could be calibrated against known tensile and compressive forces.

Dynamic coupler force data was collected during two phases of coal transportation service. During the first phase, longitudinal coupler forces were recorded as the car completed two trips between the Powder River Basin and power plants in the eastern United States. The first trip was between the Powder River Basin and New York via Union Pacific and CSX, and the second trip was between the Powder River Basin and Georgia via BNSF and Norfolk Southern. This test was completed in 2006. During the second phase of testing, coupler force data was recorded as the test car completed multiple trips between the coal mines of the Grand Junction, Colorado, area and either East St. Louis, Illinois, or Jessup, Kentucky. The second phase of testing was completed in December 2007.

Coupler force data was recorded for 100 percent of the loaded mileage during both phases of testing. Using the methods described in ASTM Standard E-1049(85), the time domain force data was processed into rainflow cycle counted histograms containing maximum and minimum values for each cycle, the total number of cycles at each maximum force/minimum force combination and the probability or percentage of occurrence for each maximum force/minimum force combination. This is the type of data currently contained in Chapter 7, Section C, Part II, Volume 1 of the Association of American Railroads *Manual of Standards and Recommended Practices* and is intended to aid car designers with fatigue strength analysis.

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INTRODUCTION AND BACKGROUND

According to the *Manual of Standards and Recommended Practices*, it has been over 20 years since any comprehensive measurement of revenue service dynamic coupler loads has been completed. That testing, completed in the 1983 to 1985 time frame, was conducted using 100-ton hopper cars in unit train and general service.

Transportation Technology Center, Inc. (TTCI) recently completed a program to measure the dynamic longitudinal coupler forces imposed on one 286,000-pound gross rail load coal hopper car as it traveled over 8,700 miles in typical revenue service operations.

Load environment data is contained in the AAR *Manual of Standards and Recommended Practices* (MSRP). It is used in fatigue strength calculations during the design of carbodies and draft system components. With the current, frequent use of 110-ton (286,000 lb. gross rail load) cars in heavy haul, unit coal train service, the American Railway Car Institute Freight Car Fatigue Task Force requires that load environment data be collected while using the 110-ton equipment.

PROCEDURE

The collection of this 286,000-pound gross rail load data was conducted in two phases. For both phases, the test car used was an aluminum hopper car with a volume capacity of 4,020 ft^3 and an empty weight of 51,900 pounds. TTCI installed strain gage transducers on one coupler and calibrated the transducer output against that of a calibrated load cell. This instrumented coupler was installed at the B-end of the test car. Phase 1 consisted of two trips between the Powder River Basin of Wyoming and power plants in the eastern United States. The first trip was over Union Pacific and CSX roads between the Powder River Basin and Dunkirk, New York. Total mileage was 1,770. The second trip was over BNSF and Norfolk Southern roads between the Powder River Basin and Sherer, Georgia. Test mileage was 1,730. These trips took place between March and May of 2006. For both Phase 1 trips, train make-up was as follows:

1. Locomotives
2. Instrumentation coach (manned)
3. Buffer coal hopper car
4. Test coal hopper car with instrumented coupler
5. Remaining coal hopper cars

Dynamic coupler force data was collected for the entire time the car was in motion. Travel speeds duplicated those used in standard service and total test mileage for both Phase 1 trips was approximately 3,500.

During Phase 2 of data collection, the test car completed a total of five trips in standard revenue service. All mileage accumulated was over UP routes. Two trips were completed between western Colorado and Jessup, Kentucky, and three trips were completed between western Colorado and East St. Louis, Illinois. During all trips, the test car was within trains of approximately 100 cars. During the trips to Kentucky, the train had distributed power for most of the distance. During the trips to east St. Louis, distributed power was present only within Colorado. During the trips to Kentucky, the test car was placed about 10 to 15 cars from the trailing end, and during the trips to east St. Louis, the test car was in the first third of the train. No other special previsions were made to accommodate this test. Since the data acquisition system was totally contained on the test car during this phase, no additional "manned" test coach was required. Test data was recorded with the car both moving and stationary, and total test mileage accumulated was approximately 5,220.

Figure 1. Test Car – Phase 1 Testing

Figure 2. Test Car & Data Acquisition System Phase 2 Testing

RESULTS

Dynamic coupler force data was recorded at a rate of at least 256 samples per second. Time domain data was converted to cycle counted histograms using the rainflow method described in ASTM Standard E-1049(85). The resulting histograms contained maximum and minimum cycle values, number of cycles for each maximum/minimum bin, and the percentage of occurrence for each maximum/minimum bin. Each bin size was 10,000 pounds. As a result, cycles of less than 10,000 pounds (minimum to maximum range) were not counted.

In order to observe the character of the data and compare results from the two different phases of data collection in 2-dimensional form, force range versus event per mile data was also created and plotted. The range is the minimum value of a cycle subtracted from the maximum value. All cycles from each range bin are then added together. The cycles for each range bin are then divided by the total test mileage for that particular channel to produce a cycle or "event per mile" number. Stress range is a significant factor in the calculation of fatigue damage. Figures 3 through 5 show the results of this kind of analysis.

Figure 3 compares the results from test Phases 1 and 2. This plot shows that between the force ranges of 70,000 to 280,000 pounds, the Phase 2 spectrum appears to be more severe than that measured during Phase 1. For example for a coupler force range of 200,000 pounds, there were over four events per 1,000 miles during Phase 1 testing and over nine such events per mile during Phase 2 testing. At force ranges lower than 70,000 pounds and greater than 280,000 pounds, however, the load environments measured during Phases 1 and 2 appear very similar. Figure 4 is a similar plot but adds the range events for the 100-ton hopper car coupler force histogram currently in Chapter 7, Section C, Part II, Volume 1 of the AAR MSRP (Ref. Table 7.3.5.4). Observation of this data indicates that the existing 100-ton load environment could be more severe than either set of Phase 1 or Phase 2 data in the magnitude of load range from 100,000 to 240,000 pounds. At the higher load ranges of about 500,000 pounds and above, however, the 110-ton environment could be more severe. For example at a force range of 540,000 pounds, the frequency of occurrence measured during Phases 1 and 2 is about 20 to 30 for every 100,000 miles, while the existing 100-ton data predicts 6 to 7 every 100,000 miles.

Figure 5 is similar to Figures 3 and 4, but compares the force range per mile data collected during this test with the 100-ton "Severe Environment" data currently in MSRP Chapter 7 (Ref. Table 7.5.5.5). Comparison of data in Figure 5 again shows that for force ranges of 140,000 to 400,000 pounds magnitude, the 100-ton severe load environment appears to be more severe than the data collected during this test.

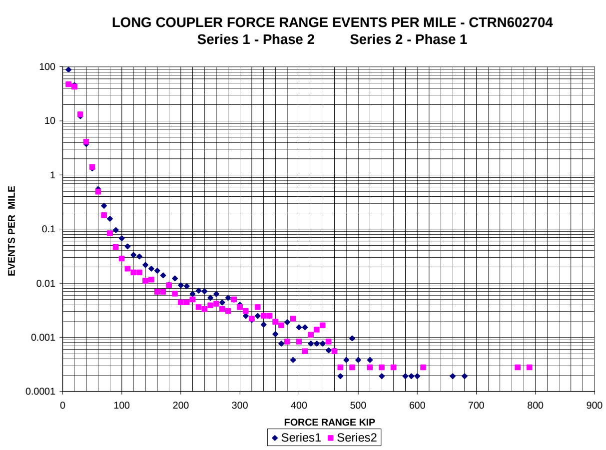

Figure 3. Coupler Force Range Events per Mile, Phases 1 and 2

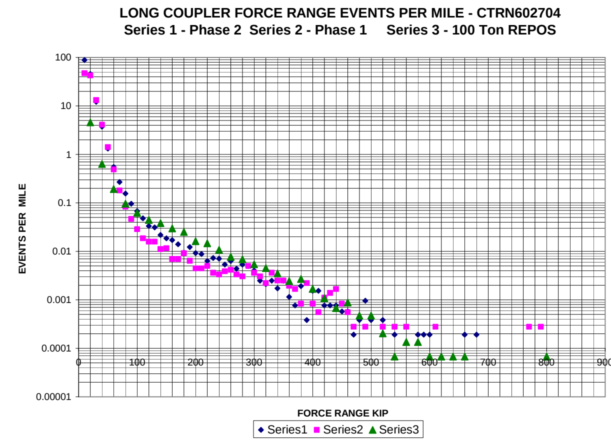

Figure 4. Coupler Force Range Events per Mile, Test Phases 1 and 2 plus 100-Ton Hopper Car Data from AAR MSRP

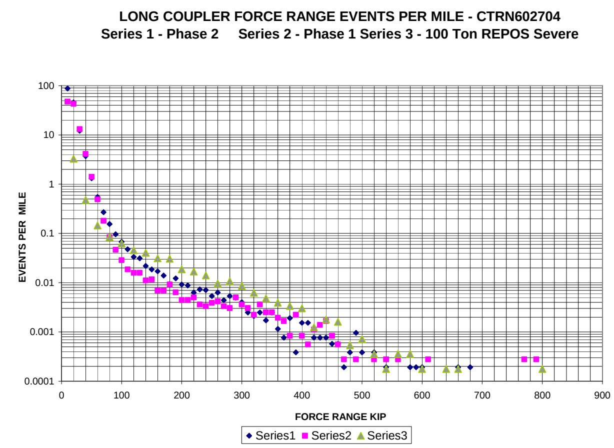

Figure 5. Coupler Force Range Events per Mile, Test Phases 1 and 2 plus 100-Ton Hopper Car Severe Environment Data from AAR MSRP

For example at a force range of 220,000 pounds, data from Phases 1 and 2 would predict 5 to 6 events or cycles per 1,000 miles; whereas, the 100-ton severe load environment predicts 16 to 17 events per 1,000 miles. At ranges higher than 400,000 pounds, data from Phases 1 and 2 is comparable to that of the 100-ton severe environment, and at ranges lower than about 100,000 pounds, there are actually significantly more cycles at each load range in the 110-ton data than for the 100-ton severe environment.

Figures 6 through 8 demonstrate another way to view the coupler force cycle data. For each cycle the mean value of that cycle was calculated. The number of cycles for each mean value was then summed over the full duration of the test. The mean value of each cycle can have an effect on fatigue damage calculations under some conditions. Figure 6 shows that the overall character of the data collected during Phases 1 and 2 was similar. But at the higher absolute values, there tended to be more cycles for Phase 1 data than for Phase 2 data. This may be a function of car placement near the head end of the train during Phase 1. Figure 7 includes the 100-ton hopper mean data and demonstrates that except for mean values of about -250,000 to -350,000 pounds (tensile or draft loads), the cycles at each mean force level are significantly lower than for the 110-ton data. Figure 8 compares the 100-ton hopper severe spectrum with the data from test Phases 1 and 2. This plot shows a similar trend as Figure 7 with even greater differences in the number of cycles between the 100- and 110-ton data at mean values between -160,000 and +160,000 pounds. These significant differences in cycles at each mean value between about -160,000 and +160,000 pounds could be a reflection of the increased tonnage of the consist when 110-ton data was collected.

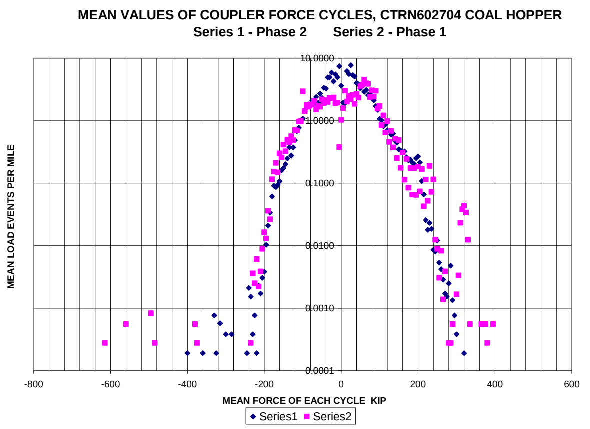

Figure 6. Coupler Force Mean Value Events per Mile, Test Phases 1 and 2

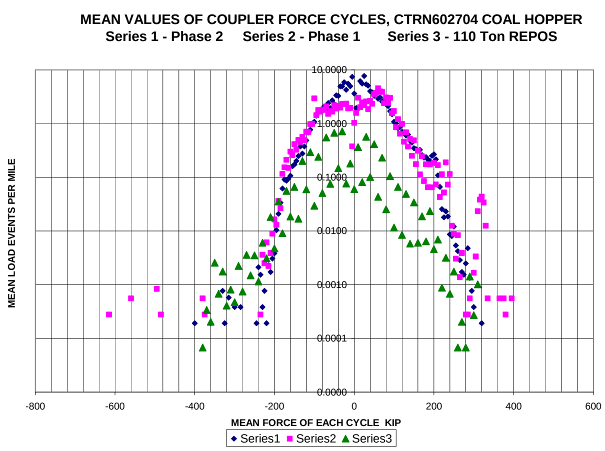

Figure 7. Coupler Force Mean Value Events per Mile, Test Phases 1 and 2 plus 100-Ton Hopper Car Data from AAR MSRP

Table 1 shows a summary of the distance or duration over which the coupler force data in this report was recorded.

Table 1. Summary of Test Mileage

TEST DATA	TEST MILEAGE
110-Ton Service, Phase 1	3,500
110-Ton Service, Phase 2	5,220
100-Ton Service	14,787
100-Ton Service, Severe Environment	5,625

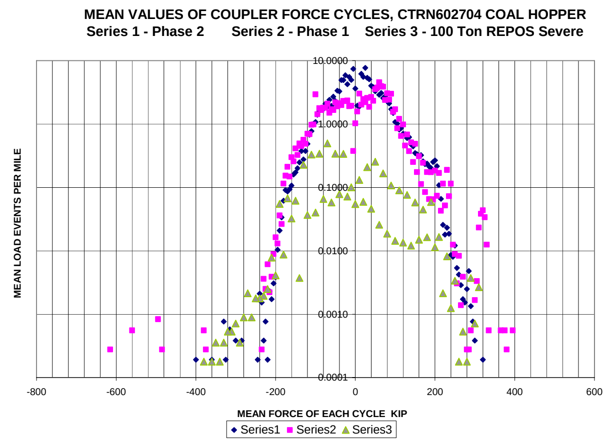

Figure 8. Coupler Force Mean Value Events per Mile, Test Phases 1 and 2 plus 100-Ton Hopper Car Severe Environment Data from AAR MSRP

SUMMARY AND CONCLUSION

This report describes the procedures used to collect a set of longitudinal coupler force data during standard heavy haul, unit train revenue service. Also presented were methods to compare the newly obtained dataset and similar data recorded in the past. These comparison methods indicate that there may be significant differences between the recently recorded 110-ton data and the existing 100-ton data. A truly definitive comparison, however, would have to include the use of both sets of data in a fatigue analysis for a section of a car structure that is significantly influenced by longitudinal coupler forces. A comparison of calculated fatigue damage would give a clear indication which set of data represents the more severe environment.

At this time, the 110-ton coupler force data includes all buff and draft load cycles. Additional processing could be done to make this data useful for the calculation of coupler knuckle fatigue damage. All buff load cycles would be set to zero to reduce the load range events to a level actually seen by the knuckle. This additional processing would allow the 110-ton environment data to be compared to previously recorded data that is currently being used to evaluate coupler and knuckle fatigue performance. Again, the preferred method to compare different knuckle load spectrums would be to perform a fatigue damage calculation using the cycle counted range-mean histograms of each.