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LOCOMOTIVE CRASH ENERGY MANAGEMENT COUPLING TESTS EVALUATION AND VEHICLE-TO-VEHICLE TEST PREPARATION

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ABSTRACT

Research to develop new technologies for increasing the safety of passengers and crew in rail equipment is being directed by the Federal Railroad Administration's (FRA's) Office of Research, Development, and Technology. Crash energy management (CEM) components which can be integrated into the end structure of a locomotive have been developed: a push-back coupler and a deformable anti-climber. These components are designed to inhibit override in the event of a collision. The results of vehicle-to-vehicle override, where the strong underframe of one vehicle, typically a locomotive, impacts the weaker superstructure of the other vehicle, can be devastating. These components are designed to improve crashworthiness for equipped locomotives in a wide range of potential collisions, including collisions with conventional locomotives, conventional cab cars, and freight equipment.

Concerns have been raised in discussions with industry that push-back couplers may trigger prematurely, and may require replacement due to unintentional activation as a result of loads experienced during service and coupling. Push-back couplers (PBCs) are designed with trigger loads meant to exceed the expected maximum service and coupling loads experienced by conventional couplers. Analytical models are typically used to determine these trigger loads. Two sets of coupling tests have been conducted that validate these models, one with a conventional locomotive equipped with conventional draft gear and coupler, and another with a conventional locomotive retrofit with a PBC. These tests allow a performance comparison of a conventional locomotive with a CEM-equipped locomotive during coupling, as well as confirmation that the PBC does not trigger at speeds below typical coupling speeds. In addition to the two sets of coupling tests, car-to-car compatibility tests of CEM-equipped locomotives, as well as a train-to-train test are also planned. This arrangement of tests allows for evaluation of the CEM-equipped locomotive performance, as well as comparison of measured with simulated locomotive performance in the car-to-car and train-to-train tests.

The conventional coupling tests and the CEM coupling tests have been conducted, the results of which compared favorably with their pre-test predictions. In the CEM coupling tests, the PBC triggered at a speed well above typical coupling speeds. This paper provides a comparison of the conventional coupling test results with the CEM coupling test results. The next test in the research program is a vehicle-to-vehicle impact test. This paper describes the test preparation, test requirements, and analysis predictions for the vehicle-to-vehicle test. The equipment to be tested, track conditions, test procedures, and measurements to be made are described. A model for predicting the behavior of the impacting vehicles and the CEM system has been developed, along with preliminary predictions for the vehicle-to-vehicle test.

BACKGROUND

The Office of Research, Development, and Technology of the Federal Railroad Administration (FRA) and the Volpe Center are continuing to evaluate new technologies for increasing the safety of passengers and operators in rail equipment. In recognition of the importance of override prevention in train-to-train collisions in which one of the vehicles is a locomotive [1, 2, 3], and in light of the success of crash energy management technologies in passenger trains [4], FRA seeks to evaluate the effectiveness of crashworthy components that are integrated into the end structure of a locomotive. These components are specifically designed to mitigate the effects of a collision and, in particular, to prevent override of one of the lead vehicles onto the other [5].

A research program has been conducted to develop, fabricate and test two crash energy management (CEM) components for the forward end of a locomotive: (1) a deformable anti-climber (DAC), and (2) a push-back coupler (PBC) [6, 7]. Detailed designs for these components were developed, and the performance of each design was evaluated through large deformation dynamic finite element analysis (FEA). Two test articles were fabricated and individually dynamically tested by means of a rail car impact into a test wall in order to verify performance characteristics of the two components relative to specific requirements. The tests were successful in demonstrating the effectiveness of the two design concepts. Test results were consistent with finite element (FE) model predictions in terms of energy absorption capability, force-displacement behavior and modes of deformation. This research program integrates the two CEM components onto a locomotive in order to demonstrate through testing that these components work together to mitigate the effects of a collision and prevent override [8].

The planned tests are based on a head-on collision scenario in which a locomotive-led train collides with a stationary train. The stationary train can be led by a conventional locomotive, a CEM locomotive, a cab car, or a freight car. The overall objective of these tests is to demonstrate the effectiveness of the locomotive CEM system, comprised of a PBC and a DAC. The first set of tests were coupling tests of a conventional F40 locomotive coupling with an M1. The second set of tests, were coupling tests of an F40 retrofitted with a PBC coupling with an M1 cab car. This arrangement of the tests allows comparison of the conventional coupler performance with the performance of the PBC. The third set of tests will be vehicle-to-vehicle impact tests of a CEM F40 (retrofit with a PBC and a DAC) impacting a stationary vehicle. The final test planned is a train-to-train impact test of a CEM F40-led train impacting a conventional stationary train.

Table 1 summarizes the critical measurements for each of the four types of tests. The first two sets of tests, the coupling tests, demonstrated that the PBC performs as expected in service. The vehicle-to-vehicle tests will demonstrate that the components work together as an integrated system to provide crashworthiness with a range of equipment, and the train-to-train test will demonstrate the effectiveness of the crashworthy components.

A series of dynamic CEM coupling tests was performed to demonstrate that the push-back coupler will, or will not, trigger, depending on the proper conditions. However, before demonstrating the robustness of the push-back coupler, it was important to establish a baseline for conventional coupling to determine the maximum non-destructive conventional coupling speed. Therefore, conventional coupling tests were conducted first [9], [10]. The results of the conventional coupling tests compared favorably with pre-test predictions. The lowest coupling speed at which damage occurred was 6 mph.

Table 1. Test descriptions and critical measurements

Test Description	Critical Measurements
Conventional Coupling Tests	• Maximum non-destructive coupling speed • Dynamic impact forces • Impact accelerations • Displacements
CEM Coupling Tests	• Maximum non-destructive coupling speed • Dynamic crush forces • Impact accelerations • Displacements • Effectiveness of PBC
Vehicle-To-Vehicle Tests	• Dynamic crush forces • Accelerations • Displacements • Effectiveness of PBC and DAC working as a system
Train-To-Train Test	• Effectiveness of crashworthy components at managing load path • Effectiveness of crashworthy components in inhibiting override and lateral buckling

The CEM coupling tests were conducted repeatedly with the same F40 locomotive and M1 passenger car, with targeted impact velocities of 2 mph, 4 mph, 6 mph, 7 mph, 8 mph, and 9 mph, or until the PBC triggered. The test requirements and pre-test analysis for these tests are detailed in a companion paper [11]. The test setup, equipment, retrofit of the F40 locomotive, test implementation, and test results are described in another companion paper [12]. This paper includes additional analysis of the results of the CEM coupling tests, as well as the test preparation, test requirements, and analysis predictions for the first vehicle-to-vehicle test. The paper concludes with a summary evaluation and a description of the next steps in the research program.

COUPLING TESTS COMPARISON & ANALYSIS

The complete test results for both the conventional coupling tests and the CEM coupling tests are detailed in two previous papers [10], [12]. In the conventional coupling tests, a total of six impact tests were conducted, with the final test conducted at a target speed of 12 mph. All actual speeds were within +/-0.3 mph of the corresponding target speed. In all but the last two tests (10 mph and 12 mph), the vehicles coupled together on impact. The vehicles remained on the tracks for all of the conventional coupling tests. In the CEM coupling tests, a total of six impact tests were conducted at target speeds of 2 mph, 4 mph, 6 mph, 7 mph, 8 mph, and 9 mph. The test was repeated and the coupling speed was increased for each subsequent test until the PBC triggered. All actual speeds were within +/-0.4 mph of the corresponding target speed. The coupling speed at which the PBC triggered was 9 mph, a speed much greater than typical coupling speeds. The vehicles coupled together on impact in only the first two tests (2 mph and 4 mph). The vehicles remained on the tracks for all of the CEM coupling tests. Table 2 summarizes the test speeds and coupling of both sets of tests. The target speeds (2 mph, 4 mph, and 6 mph) were the same for the first three tests for each series of tests. The actual test speeds were within 10% of the target speeds for all tests.

Table 2. Coupling Tests Results Comparison

Test No.	Conv. Test Speed (mph)	Conv. Vehicles Coupled?	CEM Test Speed (mph)	CEM Vehicles Coupled?
1	1.9	Yes	1.8	Yes
2	3.9	Yes	3.7	Yes
3	5.7	Yes	5.7	No
4	7.9	Yes	6.8	No
5	10.0	No	7.6	No
6	11.9	No	8.9	No

One difference between the coupling tests was that the vehicles coupled together in the 2 mph, 4 mph, 6 mph, and 8 mph for the conventional coupling tests, but only in the 2 mph and 4 mph tests in the CEM coupling tests. This is very likely due to the vertical misalignment in the couplers for the CEM tests. In the conventional coupling tests, the vehicle couplers were aligned vertically. However, in the CEM coupling tests, the vehicle couplers were initially misaligned by approximately 3 inches. This was alleviated somewhat by the M1 coupler being shimmed for these tests. The shims did not completely correct the misalignment, but brought the couplers to within 2 inches of each other vertically.

Equipment Damage

In the conventional coupling tests, after all six impacts, the only damage to the locomotive was a small chip on the coupler knuckle that occurred in the 10 mph impact. Damage to the M1 began in the 4 mph impact. Both of the traction bars (which were smaller in diameter than the original traction bars) on the front truck of the M1 bent as a result of the coupling impact. They were replaced with traction bars salvaged from another retired M1. In the 6 mph coupling impact, dimpling of the carbody shell began to occur at the front left side sill truck connection, as shown in Figure 1. This dimpling increased in size due to the 8 mph coupling impact. After the 10 mph impact, the vehicles did not couple, and there was bulging of the M1 draft sill and damage to the coupler stops due to the coupler shank pushing on the coupler stops. There was a bend in the right flange of the draft pocket, and one of the buff plates in the draft gear was bent. Buckling of the left side sill truck connection also occurred, with dimpling beginning to occur on the right side sill truck connection. In the 12 mph impact, coupling did not occur. There was a piece broken off at the front left truck connection, an underframe member was bent near the front left truck, and the front belt loop of the front truck was severed. There were cracks in both side sills at the front truck connection, and significant buckling of the left side sill at that location. Post-test inspection of the M1 draft gear revealed bent buff plates and bent interior draft pocket longitudinal members.

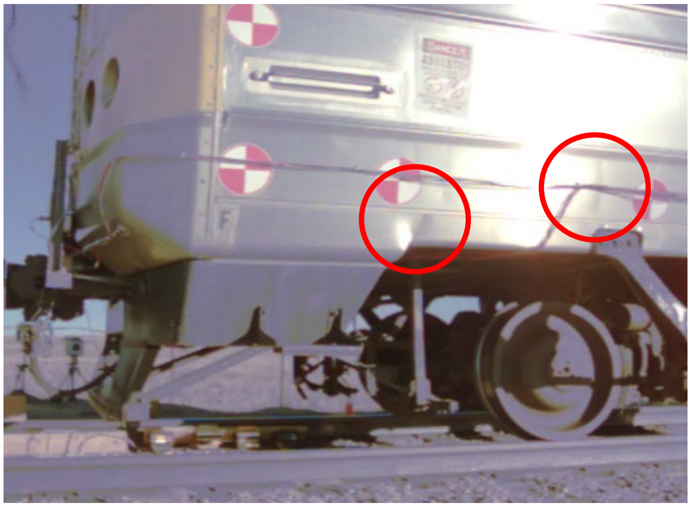

Figure 1. Conventional Coupling Test: Dimpling of M1 shell at front left side sill truck connection after 5.7 mph impact test

In the CEM coupling tests, after all six impacts, the only structural damage to the locomotive was the triggering of the PBC in the 9 mph impact, with approximately 5/8 inches of stroke experienced by the PBC. This damage can be seen in Figure 2. The front truck transom bar hit the PBC flag and bent its bolt in the 6 mph impact, but did not trigger the PBC. The front truck transom bar continued to hit the PBC flag but did not cause it to trigger through the subsequent impacts, until the PBC triggered in the 9 mph impact.

Figure 2. Cracked paint on the left side of the PBC deformation tube indicating tube crush

In terms of damage to the M1 in the CEM coupling tests, after the 6 mph impact, the traction rod on the front left truck was bent. It was replaced for the 7 mph test, bent again, and was not replaced for the subsequent tests. After the 8 mph test, there was a piece broken off at the front left truck connection, which was very similar to the piece broken off at the front left truck connection in the 12 mph conventional coupling test. The M1 side sills did not experience the severe dimpling and subsequent buckling that occurred in the conventional coupling tests. However, this was due to the lower impact speeds of the CEM coupling tests.

Test Measurements

Figure 3 compares the test results for conventional coupling tests with those of the CEM coupling tests. The figure shows the impact force with respect to impact speed for both series of tests. The results are almost identical for impact speeds of less than 6 mph. However, the results diverge at impact speeds greater than 6 mph. This is due to the draft gear system on the Voith PBC design on the CEM locomotive. The draft gear effectively limits the load of the impact until the PBC is triggered at 9 mph.

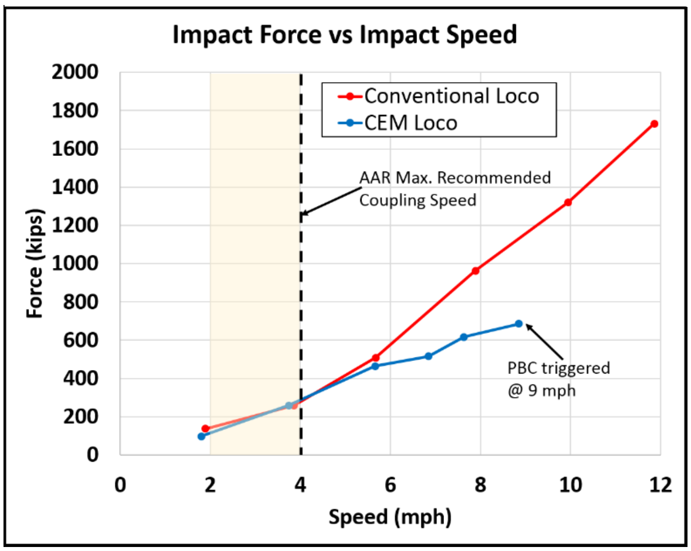

Figure 3. Impact Force vs. Impact Speed Comparison

In common practice, railroads typically couple vehicles at speeds between 2 mph and 4 mph, shown as the yellow shaded area in Figure 3. These results show that the PBC behaves very much like the conventional coupler for the complete range of typical coupling speeds. Note that triggering of the PBC occurred at a speed much greater than the maximum coupling speed recommended by the Association of American Railroads, 4 mph [13], shown as the vertical black dashed line in Figure 3. Additionally, the likelihood of coupling became less likely at the higher coupling speeds.

The CEM coupling tests successfully demonstrated the force level at which the PBC is designed to trigger. The PBC triggered at a force of approximately 670 kips, as predicted. The impact speed required to trigger the PBC was higher than previously predicted. However, this prediction was based on higher vehicle weights and a softer elastic characteristic of the draft gear in the Voith PBC. The CEM coupling tests show that for the given vehicle-to-vehicle coupling scenario, it is unlikely that the PBC will accidently trigger within the common coupling speed range. Computer models can be used to extrapolate and determine coupling speeds for other coupling scenarios. Most PBC manufacturers utilize modeling and testing to design and ensure their PBC will not trigger in coupling scenarios defined by the purchaser. Additionally, the draft gear components of the PBC can be designed to have a higher elastic capacity for cushioning higher speed coupling events to protect the PBC from premature activation.

CEM VEHICLE-TO-VEHICLE TEST REQUIREMENTS

The next test to be conducted in the locomotive crashworthiness test program will be the first of two CEM vehicle-to-vehicle tests. The CEM vehicle-to-vehicle tests will be conducted at the Transportation Technology Center (TTC) in Pueblo, Colorado. This series of tests will combine the two CEM components and retrofit them to an F40 locomotive. The CEM-retrofit F40 will then be tested by impacting a stationary vehicle, as shown in Figure 4. In preparation, the two CEM components, a deformable anti-climber (DAC), and a push-back coupler (PBC), have been retrofit onto an F40 locomotive. For this test, the CEM locomotive will impact a stationary conventional locomotive at a speed that will be estimated to fulfill the following test requirements:

1. Triggering and complete stroke of the PBC,
2. Shear bolt failure and translation of the sliding lug,
3. Absorption of at least 50% of the DAC energy absorption requirement of 600 ft-kips.

For this test, the conventional locomotive will be braked.

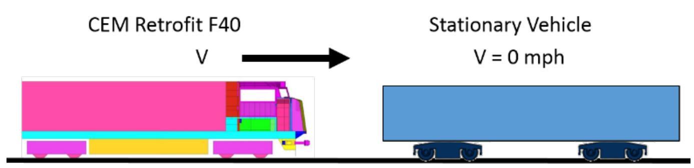

Figure 4. Schematic of CEM vehicle-to-vehicle tests initial conditions

The objective of the vehicle-to-vehicle tests is to demonstrate the effectiveness of the PBC and DAC integrated system to work together to absorb impact energy and prevent override in a vehicle-to-vehicle collision. After the first vehicle-to-vehicle test is conducted, the CEM system will be replaced with new crashworthy components, and the newly-retrofit locomotive will be used in another test with a different stationary vehicle. The tests will demonstrate the compatibility of the locomotive CEM system (the PBC and the DAC) with a range of impacting equipment, such as other locomotives, passenger cars, and freight cars. The tests will also demonstrate the reparability and serviceability of the locomotive CEM system.

The information desired from each vehicle-to-vehicle test includes the longitudinal, vertical and lateral accelerations of the equipment, the displacements of the couplers and other key structures, as well as strain information at specific locations. Information is also sought on the sequence of events, e.g., timing of the triggering of the PBC fuse, translation of the sliding lug, and deformation of the DAC crush tubes. The equipment and components will be inspected carefully after the test to ascertain the condition of the equipment and quantify the damage incurred. A post-test inspection and teardown of the CEM equipment and conventional locomotive draft gear will be conducted.

The force-crush characteristic (i.e., the load that the couplers and supporting structure develop during the impact) is a key characteristic of the couplers and the vehicles. One purpose of these tests is to take measurements for comparison with analytical predictions in order to validate that such predictions are accurate. A comparison with the measurements taken from the CEM coupling tests will also be made.

Equipment: CEM Locomotive

The equipment that will be used for the CEM vehicle-to-vehicle test will be a retrofit F40 locomotive and conventional F40 locomotive. Retrofit F40 locomotive #234 will be used in the test and can be seen in Figure 5.

Figure 5. CEM Locomotive: F40 #234 retrofit with a PBC and DAC

Figure 6 shows a close-up of the DAC and PBC retrofit to the F40 locomotive. These two components comprise the CEM system. Figure 7 shows the PBC installed within the sliding lug, and Figure 8 is an exterior view of the shear bolts, which hold the sliding lug to the draft pocket. During an impact that occurs at greater than typical coupling speeds, the PBC is triggered at approximately 670 kips. Once the fuse is triggered, the PBC absorbs energy as it pushes back at that load level. When the PBC stroke is exhausted, the shear bolts are broken by the mounting impact force at approximately 1,100 kips. This causes the sliding lug to move back. At this point, the load path transfers from the PBC completely to the DAC, which crushes in a controlled manner, thereby absorbing additional collision energy. The entire CEM system is designed to have the colliding vehicle ends engage while absorbing the energy of the collision. This minimizes lateral buckling and ramp formation due to uncontrolled crush, both of which promote override. The design development and requirements of the CEM components are detailed in [5], [6], [7]. The details of the retrofit of F40 #234 can be found in [11], [12].

Figure 6. The DAC (top) and the PBC (bottom) comprise the locomotive CEM system

Figure 7. PBC installed within the sliding lug

Figure 8. Exterior view of the shear bolts installed through the draft pocket

Equipment: Conventional Locomotive

F40 locomotive #4117 will be used as the conventional locomotive in the test and can be seen in Figure 9. This locomotive is an F40PG-2CAT. It was rebuilt by NJT (possibly in 1997) and has never been involved in testing.

Figure 9. Conventional Locomotive: F40 #4117

TEST INSTRUMENTATION

Measurements will be made with accelerometers, strain gages, displacement transducers (string potentiometers), and high speed video cameras. This instrumentation is intended to capture the gross motions of the equipment, the relative motion of the sliding lug, couplers, and draft gear, the load paths, the local deformations, and the sequence of events, e.g., coupling, stroking of the conventional locomotive draft gear, triggering of the PBC, translation of the sliding lug, and crush of the DAC. The impact speed of the CEM locomotive will be measured with radar and a reflector-based sensor.

Accelerometers

Figure 10 shows a schematic illustration of the accelerometer locations planned for the CEM locomotive carbody and trucks. Additional accelerometers will be located on the PBC and the sliding lug. The accelerometers on the carbody are intended to capture the three dimensional gross motions of the carbody – longitudinal, lateral, vertical accelerations, as well as yaw, pitch, and roll. For each test, the measured longitudinal accelerations will be used to calculate impact forces, as well as the equipment velocities and displacements. Corresponding instrumentation locations are planned for the conventional locomotive.

Figure 11 shows a photograph annotated with the locations for the accelerometers on the PBC. Note that the photograph shows the PBC from the previous CEM coupling test. The PBC will have an accelerometer on both the right and left sides that will measure longitudinal acceleration. Similarly, the sliding lug will have an accelerometer that will measure longitudinal acceleration. Accelerometers are planned for corresponding locations on the conventional locomotive, less the CEM system instrumentation.

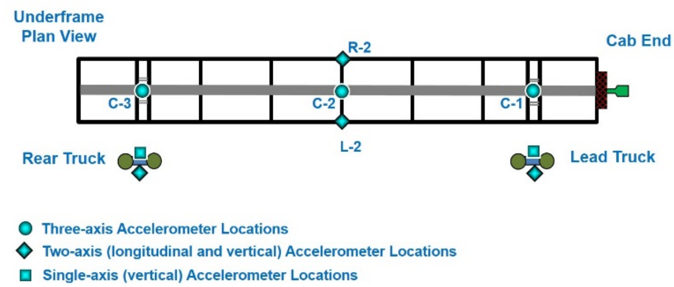

Figure 10. Schematic illustration of CEM locomotive carbody and trucks accelerometer locations

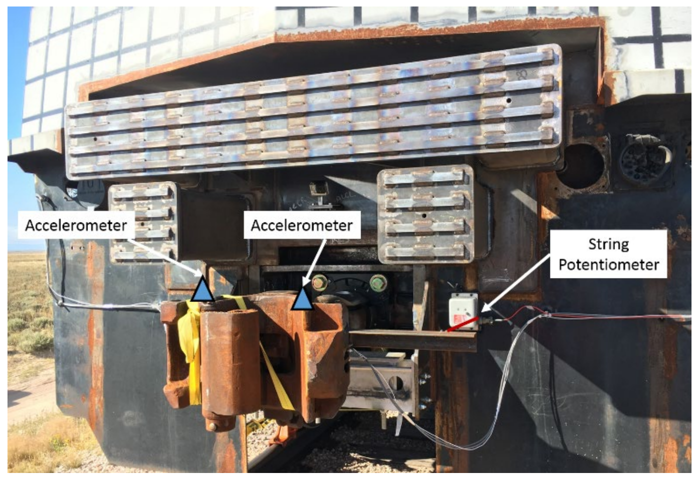

Figure 11. Photograph of locations planned for F40 locomotive coupler accelerometers and string potentiometer

Strain Gages

On both the CEM locomotive carbody and the conventional locomotive carbody, strain gages will be located on the draft pocket and center sill. On the conventional locomotive, strain gages will also be located on the coupler shank. Additionally, on the CEM locomotive, strain gages will be located on the PBC shank, the sliding lug, and the lug support. Figure 12 shows the strain gages mounted to the exterior of the CEM locomotive draft pocket for the CEM coupling test. The stain gages will be mounted the same way in this vehicle-to-vehicle test.

Figure 12. Strain gages on the CEM locomotive draft pocket exterior

Displacement Transducers

Both the CEM locomotive and the conventional locomotive will be fitted with displacement transducers on their secondary suspensions, their couplers, and their underframes. Figure 13 shows a photograph the longitudinal displacement transducer on the CEM locomotive coupler head for the CEM coupling test. Relative vertical, lateral, and longitudinal displacements will be measured. Corresponding measurements will be made of the conventional locomotive coupler. These measurements are intended to capture the longitudinal response of the conventional locomotive draft gear and PBC, and any motions that may lead to lateral buckling or override.

Figure 14 shows a photograph of the longitudinal displacement transducer intended to measure potential CEM locomotive draft sill deformation. A corresponding transducer is planned for the conventional locomotive, to measure potential deformation of the locomotive draft gear box.

In addition to the coupler and underframe displacement transducers, the vertical displacements of the secondary suspension will also be measured for both vehicles, as seen in Figure 15. The intent is to capture any pitching motion of the vehicle.

Locomotive Speed Sensors

Redundant speed sensors will measure the impact speed of the CEM locomotive when it is within 20 inches of the impact point. The speed trap is a reflector-based sensor. This technology uses ground-based reflectors separated by a known distance, and a vehicle-based light sensor that triggers as the locomotive passes over the reflectors. The last reflector is within 10 in. of the impact point. The time interval between passing the reflectors is recorded, then the speed is calculated using distance and time. Back-up speed measurement will be made with a hand-held radar gun.

Figure 13. Photograph of longitudinal displacement transducer on PBC

Figure 14. Photograph of longitudinal displacement transducer on CEM locomotive draft sill

Figure 15. Photograph of vertical displacement transducer on CEM locomotive truck

Cameras

Six high-speed (HS) and at least five real-time high definition (HD) video cameras will record the impact test conducted. Figure 16 shows a schematic of the camera locations with respect to the vehicles. All high-speed cameras are crashworthy and rated for peak accelerations of 100 g. Final alignment and sighting of the cameras will be done when the locomotives are positioned at the impact point prior to the start of test. In addition, lights will be brought in to provide illumination to the side of the vehicles when they are in shadow.

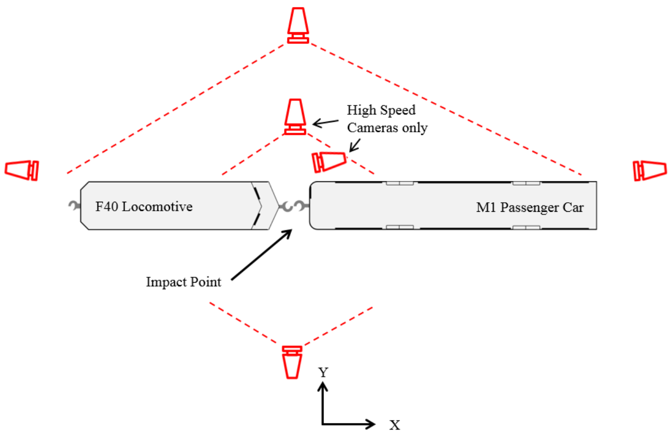

Figure 16. Schematic of camera locations

Data Acquisition

A set of 8-channel battery-powered on-board data acquisition systems will record data from instrumentation mounted on both the CEM and conventional locomotive. These systems provide excitation to the instrumentation, analog anti-aliasing filtering of the signals, analog-to-digital conversion, and recording of each data stream.

The data acquisition systems are GMH Engineering Data BRICK Model III units. Data acquisition will comply with the appropriate sections of SAE J211. Data from each channel will be anti-alias filtered at 1735 Hz, then sampled and recorded at 12,800 Hz. Data recorded on the Data BRICKS will be synchronized to time zero at initial impact. The time reference will come from closure of the tape switches on the front of each test vehicle. Each Data BRICK can take shock loading up to at least 100 g. On-board battery power will be provided by GMH Engineering 1.7 Amp-hour 14.4 Volt NiCad Packs. Tape Switches, Inc., model 1201-131-A tape switches will provide event initial contact.

Software on the Data BRICK will be used to determine zero levels and calibration factors rather than relying on set gains and expecting no zero drift. The Data BRICKS will be set to record one second of data before initial impact and seven seconds of data after initial impact.

Test Conduct

The tests will be conducted on tangent track with approximately 0.85% grade. Speed trials will be conducted to determine the distance needed to roll back the CEM locomotive for the desired impact speed. The weights of both locomotives will be measured prior to the tests. Shortly before the test the release distance will be adjusted based on wind speed and direction. Personnel will be positioned with radar guns to obtain back-up speed measurements.

After the impact test, the stopping distance will be measured. After the test, data will be downloaded to laptop computers from the on-board data acquisition system.

PRE-TEST ANALYSIS

In support of the first vehicle-to-vehicle test, in which a CEM locomotive will impact a standing conventional locomotive, a finite element (FE) analysis was conducted using the CEM locomotive and conventional locomotive models developed previously [5], [6], [7]. In this analysis, an initial CEM locomotive speed of 20 mph was imposed. This speed was chosen to fulfill the following test requirements:

1. Triggering and complete stroke of the PBC,
2. Shear bolt failure and translation of the sliding lug,
3. Absorption of at least 50% of the DAC energy absorption requirement of 600 ft-kips [5].

The final target test speed will be chosen based upon balancing the effect of weather conditions on the test day with obtaining the desired performance factors above.

The results of the FE analysis are summarized in Figure 17 through Figure 19. Figure 17 shows the final predicted deformation. The predicted maximum crush is determined to be approximately 36 inches. The end structures of the two vehicles appear to be well engaged and in-line.

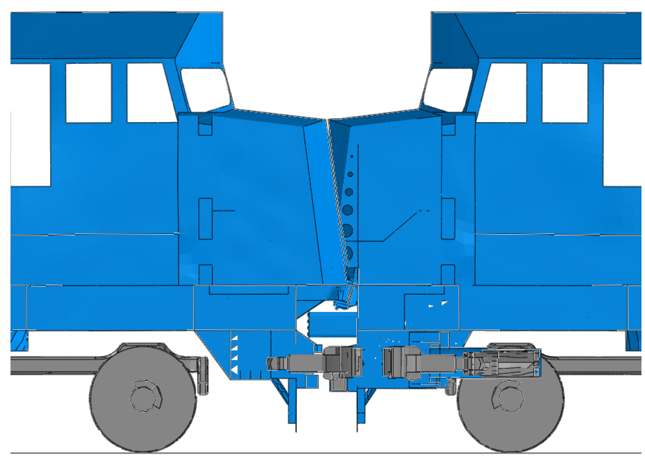

Figure 17. Predicted final deformation for CEM locomotive-to-conventional locomotive collision scenario at 20 mph

The deformation of the DAC at 32 inches and 36 inches of total crush is shown in Figure 18. The deformation of the upper tubes, which interact with the anti-climber and gusset plates of the conventional locomotive, are the primary means of DAC energy absorption. As shown in the side view, the top energy absorbing tubes are crushed at an angle due to the angled structures at the front of the conventional locomotive. The center plate remains attached to the tubes. This deformation performance is engineered to control the longitudinal impact forces and help minimize the likelihood of override. The predicted energy absorption of the DAC is determined to be approximately 420 ft-kips. This is well over half the DAC energy absorption requirement of 600 ft-kips.

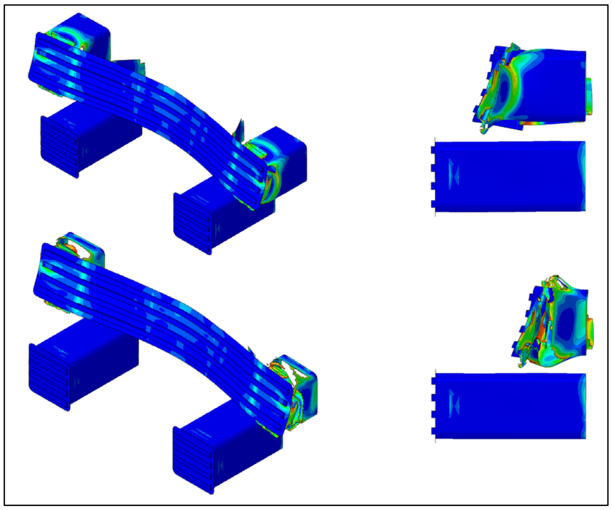

Figure 18. Predicted crush of the deformable anti-climber at 32 in. total crush (above) and 36 in. total crush (below)

The predicted force-displacement curve for the 20 mph collision is shown in Figure 19. As can be seen in the figure, the PBC triggers at approximately 5 inches of crush and 670 kips, the designed trigger load. The force then plateaus while the pushback progresses through the stroke of the PBC. At approximately 20 inches of crush, the upper DAC tubes begin to deform due to contact with the conventional locomotive underframe. The force level climbs until the shear bolts break at approximately 24 inches. The force level at this point is a combination of the force produced by the DAC tubes, the shear bolts trigger of approximately 1,100 kips, and some dynamic amplification. Note that the negative force is likely due to dynamic release of elastic energy associated with breaking of the shear bolts.

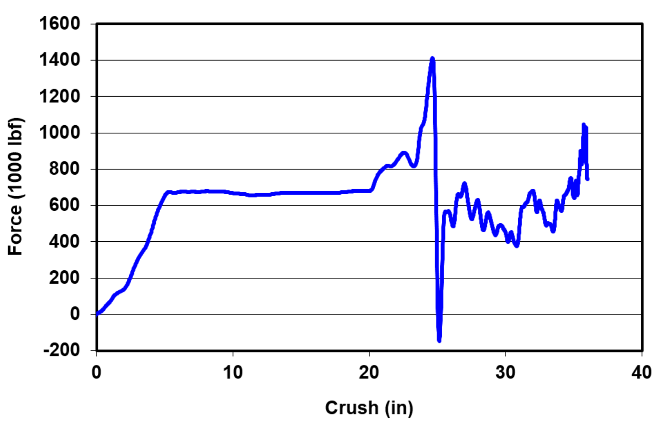

Figure 19. Predicted force-displacement curve for CEM locomotive-conventional locomotive collision scenario at 20 mph

Once the shear bolts break, the PBC is no longer in the load path. The upper DAC tubes continue to deform. As the crush continues, the upper DAC tubes begin to consolidate, causing the load to climb again.

Preparations are underway for the CEM locomotive-to-conventional locomotive vehicle-to-vehicle test. The same F40 used in the conventional and CEM coupling tests is being prepared for the first vehicle-to-vehicle test. A conventional locomotive has been chosen and is being prepared for the test. The first vehicle-to-vehicle test is projected to occur in January 2019.

SUMMARY

The FRA, with support of the Volpe Center, is conducting research on the implementation of CEM features on locomotives. These features include push-back couplers and deformable anti-climbers. A series of tests are being conducted, including coupling tests, vehicle-to- vehicle impact tests, and a train-to-train collision test. This arrangement of tests allows for comparison of conventional and CEM-equipped locomotives measured performance during coupling. Additionally, this arrangement of tests allows for evaluation of the CEM-equipped locomotive performance, as well as comparison of measured with simulated locomotive performance in the car-to-car and train-to-train impact tests.

The conventional coupling tests and the CEM coupling tests have been conducted, the results of which compared favorably with their pre-test predictions. In the CEM coupling tests, the PBC triggered at a speed well above typical coupling speeds. This paper provides a comparison of the conventional coupling test results with the CEM coupling test results. The next test in the research program is a vehicle-to-vehicle impact test. This paper described the test preparation, test requirements, and analysis predictions for the vehicle-to-vehicle test. The equipment to be tested, speed trials, test procedures, and measurements to be made were also described. A model for predicting the behavior of the impacting vehicles and the CEM system has been developed, along with preliminary predictions for the vehicle-to-vehicle test.

NEXT STEPS

Additional full-scale dynamic tests are planned which will accomplish the objectives of demonstrating that the locomotive CEM system performs well in service, provides crashworthiness compatibility with a range of equipment, and exhibits increased crashworthiness over conventional equipment. The planned tests are based on a head-on collision scenario in which a locomotive-led train collides with a stationary train. The stationary train can be led by a conventional locomotive, a CEM locomotive, a cab car, or a freight car.

The next test will be the second vehicle-to-vehicle impact test of a CEM F40 (retrofit with a PBC and a DAC) impacting a different stationary vehicle. These tests will demonstrate that the components work together as an integrated system to provide improved crashworthiness with a range of equipment. The final test planned is a train-to-train impact test of a CEM F40-led train impacting a conventional stationary train, which will demonstrate the effectiveness of the crashworthy components in a consist.

While the overall objective of these tests is to demonstrate the effectiveness of locomotive crashworthiness equipment, the test data will also be used for comparison with analyses and modeling results. The measurements will be used to refine the analysis approaches and models and assure that the factors that influence the response of the equipment are taken into account.

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