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LOCOMOTIVE CRASH ENERGY MANAGEMENT VEHICLE-TO-VEHICLE IMPACT TEST RESULTS

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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. Two crash energy management (CEM) components that can be integrated into the end structure of a locomotive have been developed: a push-back coupler (PBC) and a deformable anti-climber (DAC). 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 and compromise the occupied space. The objective of this research program is to demonstrate the feasibility of these components in improving 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, or may require replacement due to unintentional activation as a result of loads experienced during service and coupling. PBCs are designed with trigger loads which 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 provide a basis for comparing the coupling performance of a CEM-equipped locomotive with that of a conventional locomotive, as well as confirmation that the PBC triggers at a speed well above typical coupling speeds and at the designed force level. In addition to the two sets of coupling tests, two vehicle-to-vehicle collision tests where one of the vehicles is a CEM-equipped locomotive and a train-to-train collision test are planned. This arrangement of tests allows for evaluation of CEM-equipped locomotive performance, and enables comparison of actual collision behavior with predictions from computer models in a range of collision scenarios.

This paper describes the results of the most recent test in the research program: the first vehicle-to-vehicle impact test. In this test, a CEM-equipped locomotive impacted a stationary conventional locomotive. The primary objective of the test was to demonstrate the effectiveness of the components of the CEM system in working together to absorb impact energy and to prevent override in a vehicle-to-vehicle collision scenario. The target impact speed was 21 mph. The actual speed of the test was 19.3 mph. Despite the lower test speed, the CEM system worked exactly as designed, successfully absorbing energy and keeping the vehicles in-line, with no derailment and no signs of override. The damage sustained during the collision is described. Prior to the tests, a finite element model was developed to predict the behavior of the CEM components and test vehicles during the impact. The test results are compared to pre-test model predictions. The model was updated with the conditions from the test, resulting in good agreement between the updated model and the test results. Plans for future full-scale collision tests are discussed.

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 retrofit onto 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 individually 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 capacity, force-displacement behavior, and modes of deformation. In this research program, the two CEM components are integrated into the end structure of a locomotive in order to demonstrate through testing that these components work together to mitigate the effects of a collision and prevent override [8].

Each of the locomotive tests that have or will be conducted as part of this research program 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 series of tests looked at coupling at increasing speeds between a conventional F40 locomotive and an M1 cab car. The second series of tests looked at coupling increasing speeds between an F40 locomotive retrofitted with a PBC and an M1 cab car. This test sequence allows for a direct comparison of the coupling performance of a locomotive fitted with a PBC to that of a locomotive fitted with a conventional coupler. In the third series of tests, a CEM–equipped F40 locomotive (retrofit with a PBC and a DAC) impacts a stationary vehicle. In the final test that is planned, a train led by a CEM-equipped F40 locomotive will collide with a conventional stationary train.

Table 1 summarizes the critical measurements for each of the four types of tests. The first two series of tests have been completed, and demonstrate that the PBC performs as expected in service. The vehicle-to-vehicle tests — the first of which has been completed and is described in this paper — 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.

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 conventional coupling tests were conducted first to establish the speed at which coupling does not cause damage to either of the colliding vehicles [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. The objective of the CEM coupling tests was to demonstrate that the push-back coupler will, or will not, trigger, depending on the proper conditions.

The CEM coupling tests were conducted using the same F40 locomotive (now retrofit with the two CEM components) and the same M1 passenger car. Coupling tests were performed at target collision speeds of 2 mph, 4 mph, 6 mph, 7 mph, 8 mph, and 9 mph. The speed at which the PBC triggered was 9 mph. The test requirements and pre-test analysis results 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].

The first of two planned vehicle-vehicle impact tests was completed in January 2019. In this test, a CEM-equipped locomotive impacted a stationary conventional locomotive. The primary objective of the test was to demonstrate the effectiveness of the components of the CEM system in working together to absorb impact energy and prevent override in a vehicle-to-vehicle collision scenario. The test preparation, test requirements and pre-test analysis for these tests are detailed in a companion paper [13]. This companion paper includes additional analysis of the results of the CEM coupling tests.

This paper describes the test setup, equipment preparation, test implementation, and test results of this first vehicle-to-vehicle test. The results of the test are then compared to pre-test FE model predictions. The paper concludes with a summary evaluation of the test results and a description of the next steps in the research program.

TEST SCENARIO: COUPLING IMPACT

The vehicle-to-vehicle test was conducted at the Transportation Technology Center (TTC) in Pueblo, Colorado on January 23, 2019. In this test, a CEM-equipped locomotive impacted a stationary conventional locomotive. Details of the test preparation, test requirements, and pre-test analysis can be found in a previous companion paper [13].

Test Setup

The CEM-equipped locomotive used in the CEM coupling test [11], [12] was also used in this vehicle-to-vehicle test. The PBC that was activated and deformed in the previous test was replaced with a new PBC. There was no other structural damage that needed repairing. The DAC component was not damaged in the previous test and so was not replaced. In this test, a moving CEM-equipped locomotive impacted a stationary conventional F40 locomotive, as shown in Figure 1. Informed by FE model results, the target impact speed was set at 21 mph with the objective of fulfilling the following test requirements:

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

The conventional locomotive was braked.

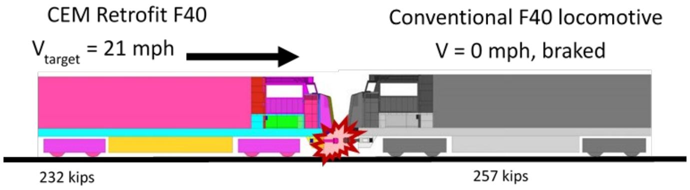

Figure 1. Schematic of CEM vehicle-to-vehicle tests initial conditions

The objective of this vehicle-to-vehicle test was 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. For the second vehicle-vehicle test, the two CEM components will be replaced and repairs will be made to any other damaged structures on the end frame of the CEM locomotive. A different type of vehicle (likely a cab car or a freight car) will be selected as the stationary vehicle. The objective of the two tests is to 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 end structures, as well as the extent of strain on the surface of key structural elements 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 each 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 behavior (i.e., the load that the couplers and supporting structure develop as the two vehicle ends deform 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 was used in the CEM vehicle-to-vehicle test is an F40 locomotive retrofit with the two CEM components, and a conventional F40 locomotive. Locomotive #234 is shown in Figure 2, with the retrofit CEM components: the PBC and DAC.

Figure 2. CEM Locomotive: F40 #234 retrofit with a PBC and DAC

Figure 3 shows a close-up of the DAC and PBC retrofit to the F40 locomotive. These two components comprise the CEM system. Figure 4 shows the PBC installed within the sliding lug, and Figure 5 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 goal is for the following sequence of events to occur. The deformation tube of the PBC begins to deform permanently at a trigger force of approximately 670 kips. It then pushes back at that load level, absorbing a substantial amount of energy. When the PBC stroke is exhausted, the back of the coupler head impacts the limit stop (a feature at the front of the sliding lug), causing a sudden increase in load to approximately 1,100 kips, which activates the failure of the 12 shear bolts. This causes the sliding lug to push back into a 10” long pocket behind it. Prior to exhaustion of the PBC stroke, the DAC impacts the anti-climbing structure of the conventional locomotive. Once the shear bolts break, the load path transfers completely from the PBC to the DAC, which then crushes in a controlled manner, 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 3. The DAC (top) and the PBC (bottom) comprise the locomotive CEM system

Figure 4. PBC installed within the sliding lug

Figure 5. Exterior view of the shear bolts installed through the side plates of the draft pocket and into the side plates of the sliding lug

Equipment: Conventional Locomotive

Locomotive #4117 was used as the conventional locomotive for the test and can be seen in Figure 6. This is an F40PG-2CAT. It was rebuilt by Conrail in 1997 and has never been previously used in testing.

Figure 6. Conventional locomotive: F40 #4117

Instrumentation

Measurements were made with accelerometers, strain gages, displacement transducers, and high-speed video cameras. This instrumentation was used to capture the gross motions of the equipment, the relative motion of the couplers and draft gear, the local deformations and load paths, and the sequence of events, e.g., coupling, compression of the draft gears, and gross structural damage. The collision speed was measured with radar and a reflector-based sensor.

Figure 7 shows a schematic illustration of the accelerometer locations for the CEM locomotive. Accelerometers were placed in similar locations on the conventional locomotive. The accelerometers on the carbody capture the three-dimensional gross motions of the carbody – longitudinal, lateral, and vertical accelerations, as well as yaw, pitch, and roll.

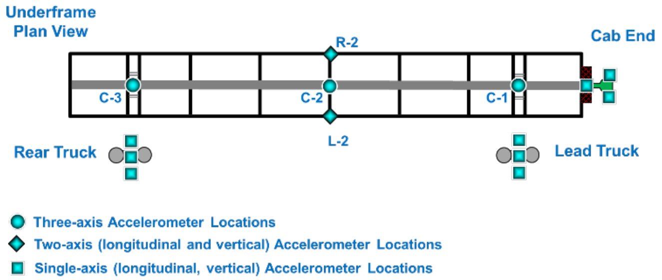

Figure 7. Schematic illustration of CEM locomotive accelerometer locations

Displacement transducers and strain gages were employed to measure local structural deformations and load paths. Forty-three accelerometer channels, forty-six strain gage channels, and twenty-two displacement transducer channels were utilized for each vehicle, resulting in 111 total data channels for the tests.

Six high-speed (HS) and five real-time high definition (HD) video cameras documented the impact. The test was conducted on tangent track with approximately a 0.85% grade. The CEM locomotive was rolled back from the conventional locomotive and released from the appropriate location to develop the intended impact speed. Speed trials were conducted prior to the test date to determine the distance needed to roll back the locomotive for the target impact speed. Shortly before the test, the release distance was adjusted based on wind speed and direction. Figure 8 shows the two locomotives prior to the test. After the impact test, the stopping distance was measured and the test data was downloaded to laptop computers from the on-board data acquisition system.

Figure 8. Pre-test photo of conventional locomotive (left) and CEM locomotive (right)

TEST RESULTS

On the day of the test, the weather conditions were clear with low winds. It was decided that both couplers would be left open in order to increase the chance of coupling, and the couplers were aligned within 1 inch vertically. The target impact speed was 21 mph, and the actual impact speed was 19.3 mph. Figure 9 shows the vehicles after the test. The vehicles were kept in-line. There was no derailment of the vehicles and no sign of override.

Figure 9. Post-test photo of the locomotives

During the test, the couplers engaged at impact, but did not lock together. The PBC triggered properly and moved back into the draft pocket. As the PBC moved back, the coupler carrier broke away, as designed. The intact coupler carrier before the test is shown in Figure 10. Figure 11 shows the failed coupler carrier where it fell after the PBC moved through it.

Figure 10**. Pre-test photograph of the coupler carrier**

Figure 11. Post-test photograph showing the coupler carrier lying on the track

After pushing through the coupler carrier, the PBC continued to move back, deforming the crush tube. Figure 12 and Figure 13 show the back of the deformation tube of the PBC before and after the impact. The deformation tube is covered in paint that is designed to peel off in strips as the exterior tube deforms. Figure 13 indicates that the stroke of the deformation tube was almost exhausted. Figure 14 shows the deformation tube after it was removed from the draft pocket. Measurements taken confirmed that the 21” design stroke of the deformation tube was indeed nearly exhausted. This was confirmed by evidence of contact between the limit stop mounted on the sliding lug and the rear of the PBC head, as shown in Figure 15 and Figure 16. This contact is designed to occur at the full stroke of the PBC.

Figure 12. Pre-test photograph of the PBC

Figure 13. Post-test photograph showing the back of the deformation tube

Figure 14. Deformed PBC deformation tube removed from the draft pocket

Figure 15. Damage to the limit stop mounted to the front of the sliding lug due to contact by the back of the PBC coupler head

Figure 16. Damage to rear of the PBC coupler head from limit stop contact

As the PBC was pushed back, the top DAC tubes impacted the front of the conventional locomotive and began to crush. Figure 17 shows the two locomotives engaged after the impact. The photo on the right shows that only the upper DAC tubes crushed, the lower DAC tubes did not deform, as expected.

For comparison, Figure 18 shows the undeformed DAC before the test, and Figure 19 shows the deformed DAC after the test, and after the vehicles had been separated. Figure 20 shows side views of both the right and left upper DAC tubes. The crush was greater on the right side than on the left. This was due to an approximately 2-inch lateral offset between the locomotives at the moment of impact.

The shear bolts connecting the sliding lug to the draft pocket did not trigger, therefore the sliding lug did not slide back into the draft pocket.

Figure 17. Post-test photo of CEM system; close-up on the right

Figure 18. Pre-test photograph of DAC

Figure 19. Post-test photograph of DAC showing that only the upper DAC tubes deformed

Figure 20. Deformed upper DAC tubes, right and left sides

Damage to the Equipment

Other than the damage that occurred to the CEM components, which was designed to occur, there was minimal damage to the CEM locomotive. Figure 21 shows the small amount of deformation of the bottom of the short hood. This is minor and easy to repair.

Figure 21. CEM locomotive damage

There was also minimal damage to the conventional locomotive. Figure 22 and Figure 23 show the dent caused by interaction with the short hood of the CEM locomotive. This is also minor and easy to repair.

Figure 22. Conventional locomotive damage

Figure 23. Close-up of conventional locomotive damage

Test Data

Accelerometer and strain gage data, shown in Figure 24 and Figure 25, suggest that complete impact of couplers did not occur until approximately 0.031 seconds after initial impact. At a speed of 19.3 mph, this suggests additional travel of approximately 10.5” prior to impact. String pot data indicate that the upper DAC assembly impacts the skirt of the conventional locomotive after approximately 0.075 seconds. This is corroborated by the significant jump in acceleration of the car bodies accompanying the impact of the anti-climbers at 0.075 seconds. The acceleration pulse drops to near zero after about 0.175 seconds.

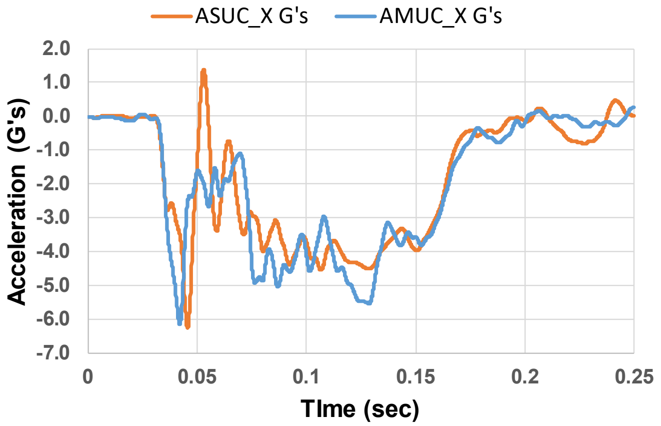

Figure 24. Car body CG accelerations of stationary (ASUC) and CEM (AMUC) locomotives

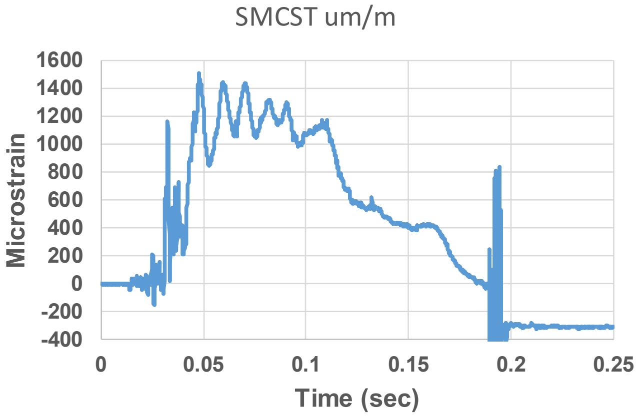

Figure 25. Strain at top of CEM coupler shank

Plotting the vehicle speed curves together, as shown in Figure 26, indicates that the maximum crush of the vehicles occurs after about 0.157 seconds. There is an abrupt change in the rate of decrease in CEM locomotive speed at 0.075 seconds due to impact of the DAC.

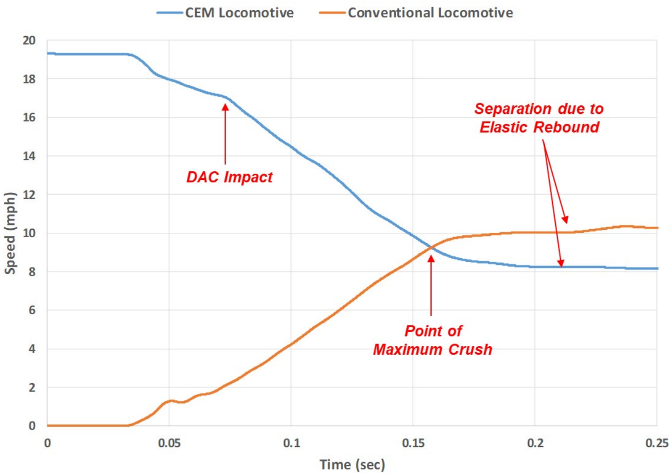

Figure 26. CEM and conventional locomotive speeds

It was determined that the relative displacement of the locomotives peaks after 0.157 secs at 34.1 inches. Subtracting the displacement prior to full coupler impact yields a peak crush distance of 23.6 inches. This 10.5” difference is consistent with the travel (11”) that occurs when the couplers are open and the knuckles move past one another and rotate before the respective vehicles fully engage, as illustrated in Figure 27. These distances have been verified by TTCI. (The 0.5” difference may be due to the thickness of the impact tape). The 23.6” inch maximum crush is consistent with full exhaustion of PBC stroke (21”) plus 2–3 inches of draft gear compression in the conventional locomotive.

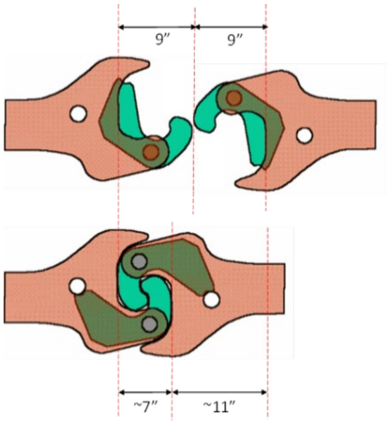

Figure 27. Coupler engagement dimensions

TEST ANALYSIS

In support of the first vehicle-to-vehicle test described above, an FE analysis was conducted using models for the CEM locomotive and the conventional locomotive 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. Impact of the PBC with the sliding lug,
3. Shear bolt failure and translation of the sliding lug,
4. Absorption of at least 50% of the DAC energy absorption requirement of 600 ft-kips [5].

The target test speed of 21 mph was chosen based upon the tolerance given by TTCI of +/-1 mph for achieving the target speed, as well as the effect of weather conditions on the test day to obtain the desired performance factors above. The actual test speed was 19.3 mph, which is below the minimum estimated speed of 20 mph to achieve all of the test requirements. During the test, the PBC was triggered and reached its complete stroke, and the PBC did impact the sliding lug, but the shear bolts did not fail and the sliding lug did not move back. For this same reason, the energy absorbed by the DAC in the impact was approximately 260 ft-kips, a little less than the target of 300 ft-kips.

Figure 28 shows the predicted deformation. Comparing it to Figure 9 and Figure 17 shows very good agreement between prediction and test result. In both the prediction and the test, the end structures of the two vehicles are well engaged and in-line.

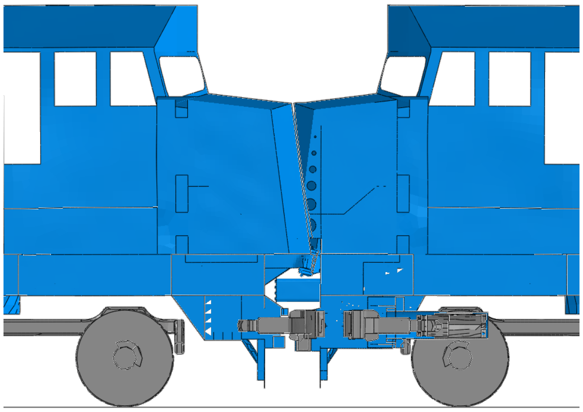

Figure 28. Predicted final deformation for CEM locomotive-to-conventional locomotive collision scenario at 20 mph

The longitudinal acceleration can be multiplied by the mass of the CEM locomotive (232,600 lb.) to estimate the longitudinal force. Figure 29 shows the force versus crush through the car body and through the coupler, from both the pre-test prediction and the test data. The solid blue line is the accelerometer-based force from the CG of the carbody. The solid red line is the strain-based force from the coupler shank, which gives a better estimate of the force through the push-back coupler. As seen in the figure, the average force through the CEM locomotive carbody (solid blue line) increases considerably — from an average of about 450 kips (when the PBC deformation tube alone is absorbing energy) to an average of about 1,000 kips (when the DAC assembly is impacted). While the estimated carbody force is about 450 kips during the PBC deformation, the coupler force (solid red line) is approximately 670 kips, which is the designed force level of the PBC push back.

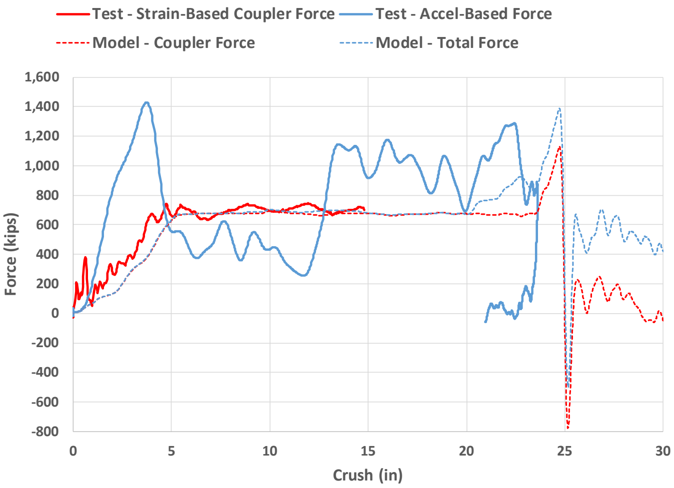

Figure 29. Force versus crush comparison of pre-test predictions with test results

A comparison of the force-crush behavior from the test and the pre-test model indicates clearly that, in the test, the DAC tubes begin to absorb collision energy much earlier than they are predicted to in the model. This is primarily due to the 10.5" or so of travel prior to loading the PBC, which causes the DAC assembly to engage earlier relative to PBC crush.

There are several reasons for the differences between model predictions and test results. The collision speed was lower than expected. A target speed of 21 mph compared to the actual speed of 19.3 mph represents a 15% decrease in collision energy. In addition, in the model, the couplers were assumed to be closed. Having the couplers open in the test brings the DAC system much closer to impact with the conventional locomotive end frame prior to PBC impact; it therefore absorbs much more energy prior to shear bolt failure. Additionally, a couple of issues related to the manner in which the DAC structures are modeled were uncovered; these likely had only a minor influence on results, but can help improve future simulations.

The FE model was modified to address these issues. Figure 30 shows a comparison of the locomotive speeds of the updated model with the test results. There is very good agreement between the test results and the updated model.

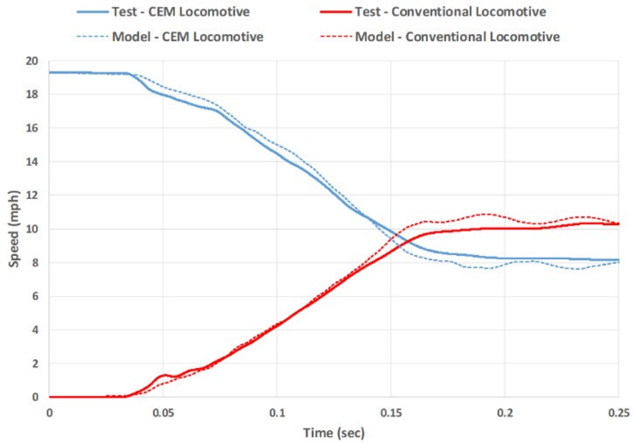

Figure 30. Locomotive speeds comparison of updated model results with test results

A comparison of the force-crush behavior from both the updated model and the test results is shown in Figure 31. Again, the solid red line is the strain-based coupler force, the solid blue line is the acceleration-based force at the CG of the CEM locomotive, the red dashed line is the model coupler force, and the dashed blue line is the model total force. As seen in the figure, the initial peak in the strain-based force (solid red line) indicates the couplers impacting. The acceleration-based estimate (solid blue line) of peak force at impact is delayed with respect to the strain-based estimate. The acceleration-based estimate of force is not as reliable as the strain-based estimate of force, particularly in the early stages of the collision. It relies on the assumption that the locomotive is behaving as a single-degree-of-freedom system, with force equal to mass multiplied by acceleration. When the vehicles first impact one another, the effective mass associated with the measured acceleration of the vehicle center of gravity is likely much lower than the total mass of the locomotive. However, the acceleration-based estimate is more reliably predicting the total force by the time the DAC is engaged.

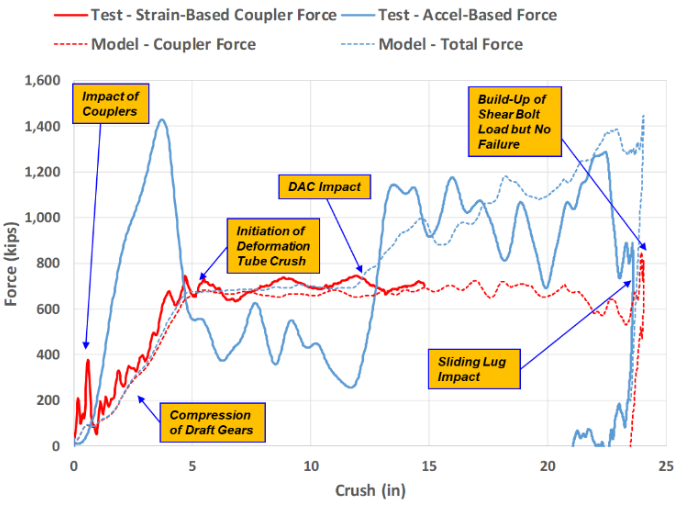

Figure 31. Force versus crush comparison of updated model results with test results

There is good agreement between the model and the strain-based measurement during the compression of the draft gears of both locomotives. Then the PBC triggers and the deformation tube begins to crush. Again, there is good agreement here between the model and the strain-based measurement. Once the DAC is impacted by the conventional locomotive, the force levels increase. This is captured by the model and the acceleration-based measurement, but not in the strain-based measurement through the coupler shank, as expected. The force levels and the fluctuation in amplitude due to the DAC tubes deforming are very similar when comparing the model and the acceleration-based measurement. The model results also indicate a build-up of force near the end of crush indicating that the load on the shear bolts is increasing, but not by enough to cause failure.

Overall, the agreement between the model results and the test results is good. The timing of the impact of the DAC is similar. The extent of the PBC deformation is similar. The mode of the DAC deformation is similar. The FEA predicts a build-up shear bolt force to about 960 kips (80 kips per bolt). This indicates that they were very close to failing (which would occur at a force of 1056 kips), but did not fail.

There are a few potential causes for the small discrepancies present between the model results and the test results. The model may not be capturing the exact extent of the conventional draft gear compression prior to the build-up to the PBC trigger load of 670 kips. There was a 2”-3” lateral and about a 3” vertical offset of the underframes of the locomotives at the moment of impact. This is evident in the difference in deformation crush of the right and left DAC tubes, as well as in the high-speed videos. In the model, the locomotive underframes are aligned laterally and vertically.

The vehicle-to-vehicle impact test demonstrated that the CEM system worked as designed. The CEM components absorbed the collision energy while successfully keeping the vehicles in-line, with no derailment and no signs of override.

SUMMARY

The FRA, with support of the Volpe Center, is conducting research on the implementation of CEM features on locomotives. These features include PBCs and DACs. A series of tests are being conducted for the program, 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 describes the results of the most recent test in the research program: the first vehicle-to-vehicle impact test. In this test, a CEM-equipped locomotive impacted a stationary conventional locomotive. The primary objective of the test was to demonstrate the effectiveness of the components of the CEM system in working together to absorb impact energy and to prevent override in a vehicle-to-vehicle collision scenario. The target impact speed was 21 mph. The actual speed of the test was 19.3 mph. Despite the lower test speed, the CEM system worked exactly as designed, successfully absorbing energy and keeping the vehicles in-line, with no derailment and no signs of override. The damage sustained during the collision is described. The test results are compared to pre-test model predictions. The model was updated with the conditions from the test, with good agreement between the updated model and the test results.

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 within a train 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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