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LOCOMOTIVE CRASH ENERGY MANAGEMENT TEST PLANS

Patricia Llana
Volpe National Transportation Systems Center
United States Department of Transportation
Cambridge, Massachusetts, USA

ABSTRACT

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. 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. Crashworthy components which can be integrated into the end structure of a locomotive have been developed to inhibit override in the event of collision. Recent research has resulted in the development of a design concept, including evaluation with finite-element analysis (FEA), fabrication, and component tests. The design concept developed incorporates two key components: a push-back coupler and a deformable anti-climber. Detailed designs for these components were developed and the performance of the designs was evaluated through large deformation dynamic FEA. Test articles were fabricated and dynamically tested to verify their individual performance characteristics. The tests were successful in demonstrating the required performance of the components. Test results were consistent with finite element model predictions of energy absorption capability, force-displacement behavior, and modes of deformation.

Work is ongoing to retrofit these crashworthy components onto conventional locomotives and conduct full-scale dynamic impact tests of colliding cars, as well as colliding trains. Service tests will be performed to measure the impact speed at which push-back coupler triggering occurs. Vehicle-to-vehicle tests will be conducted to demonstrate the performance of the crashworthy components working together as an integrated system. The vehicle-to-vehicle tests will also allow an evaluation of the crashworthiness compatibility of a modified locomotive with a range of equipment, including conventional locomotives, cab cars, and freight cars. Train-to-train tests are planned to demonstrate incremental improvement, increased crashworthiness, compatibility, and serviceability.

This paper describes the tests that are planned to demonstrate the behavior of these components when they are integrated into the end structure of a locomotive. The tests will demonstrate the in-service and crashworthiness performance of the modified locomotives. This research program endeavors to advance locomotive crashworthiness technology and develop the technical basis for generating specifications for push-back couplers and deformable anti-climbers.

INTRODUCTION

Locomotive crashworthiness research is being conducted as part of the Federal Railroad Administration's (FRA) Equipment Safety Research program. The approach of the program is to review relevant accidents and identify structural candidates for design modifications. Analytical tools and testing techniques are used to evaluate the effectiveness of these candidates. The crashworthiness research approach follows the methodology illustrated in Figure 1, which begins with developing a baseline measure of existing design performance for a given scenario and extends to developing improvements for enhancing safety performance for that scenario. The current stage of research is focused on evaluating locomotive crashworthy component designs under dynamic impacts.

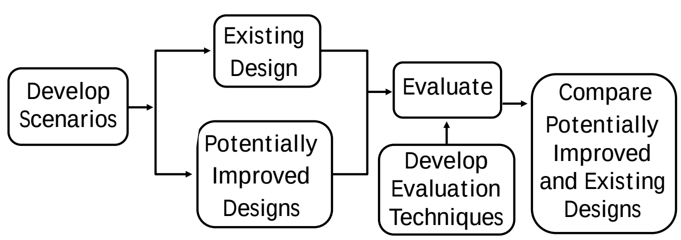

Figure 1. Flow Diagram of Crashworthiness Research Methodology

In the event of a collision between two trains, a considerable amount of energy must be dissipated. One of the potential consequences of such a collision is override of one of the vehicles onto the other. Locomotives, because of their great longitudinal strength and stiffness, are particularly susceptible to override when they collide with another vehicle, the consequences of which can be catastrophic. Research has shown that conventional anti-climbing structures can deform on impact and form a ramp, increasing the likelihood of override [1]. As they crush longitudinally, conventional anti-climbers lose their vertical load-carrying capacity due to the substantial fracture that occurs as the anti-climber crushes. The longitudinal crush of the anti-climber causes fracture in the webs behind the face of the anti-climber. These fractured webs can still resist a longitudinal compression load, but can no longer transmit a vertical shear load. This loss of vertical load-carrying capacity in conventional anti-climbers often leads to ramp formation, which promotes override. Such behavior was exhibited in a 23-mph collision that occurred in Red Oak, Iowa on April 17, 2011 [2].

Figure 2. Red Oak, Iowa Collision, April 17, 2011

As seen in Figure 2, the accident resulted in several maintenance-of-way equipment cars overriding the impacting locomotive. The photograph shows the impacting locomotive's modular crew cab was detached and partially crushed as a result of being overridden, resulting in two fatalities. In order to be effective, an anti-climber must engage the end structures of opposing equipment and provide sufficient vertical load-carrying capacity to prevent such override.

Research has also shown that the addition of a few structural features to the forward end of a locomotive can greatly reduce the propensity for override [3]. These features include the following:

1. Push-back couplers, and
2. Deformable anti-climbers.

Push-back couplers allow the ends of the vehicles to engage prior to the build-up of large forces and moments that might lead to lateral buckling of the vehicles with respect to one another. Deformable anti-climbers provide sufficient vertical load-carrying capacity as they deform gracefully and predictably to prevent the formation of a ramp. Crushable zones within deformable anti-climbers absorb collision energy so as to prevent uncontrolled deformation of interlocking features that might cause formation of a ramp.

Structural features such as these that are specifically put in place to mitigate the effects of a collision are common in rail vehicles that are designed according to the principles of crash energy management (CEM). CEM is a design strategy aimed at increasing occupant survivability during a collision, and is based on the notion that the energy of a collision can be dissipated in a controlled manner through the use of crush zones and other structural features.

The Volpe Center is supporting the Office of Research and Development of the FRA in the development of a CEM system for locomotives. In a previous research program, the Volpe Center developed several concepts for a more crashworthy locomotive [3]. The study addressed the feasibility of incorporating push-back couplers and deformable anti-climbers into locomotives. Conceptual design goals included the preservation of occupant volume and the maintenance of vehicle-rail contact, i.e., the prevention of override, while ensuring that the equipment was compatible with existing operating requirements. Building on this previous work, the objectives of the recently completed research program were to: (1) develop detailed designs for a push-back coupler and a deformable anti-climber; (2) develop test article designs for the components; (3) fabricate the test articles; (4) conduct the component tests; and (5) if necessary, refine the designs based on the results of the tests.

The development of the component designs is detailed in a companion paper [4]. The finite element analyses of the component designs are detailed in a second companion paper [5]. A third companion paper describes the sub-component analyses and tests, the design and analyses of the full-scale test articles, and includes results from the full-scale dynamic tests [6]. The results of the dynamic tests were compared to the design requirements and the pre-test finite element predictions. Both crashworthy component designs met the design requirements and the tests were successful in demonstrating the effectiveness of the two design concepts individually. Test results were consistent with finite element model predictions in terms of energy absorption capability, force-displacement behavior and modes of deformation.

The overridden locomotive involved in the Red Oak accident was compliant with the latest regulations, specifically AAR S-580 [7]. When these regulations were adopted, push-back couplers and deformable anti-climbers were discussed, but the technology was not sufficiently mature. This research program endeavors to develop this technology further.

ONGOING RESEARCH

The objectives of the locomotive crashworthiness research program are to demonstrate that the locomotive crashworthy integrated system, combining the push-back coupler (PBC) and deformable anti-climber (DAC), performs as expected in service, provides crashworthiness compatibility with a range of equipment, and exhibits increased crashworthiness over conventional equipment. The first step in the process was the design of the locomotive crashworthy components, completed recently. The locomotive crashworthy components were designed to be retrofit to a MotivePower MPXpress MP40PH-3C (MP40), a fairly new locomotive built initially in 2007 that is currently in operation in Toronto, Ontario and Seattle, Washington. Figure 3 shows the computer model of the deformable anti-climber (DAC) and push-back coupler (PBC) designs retrofit to an MP40. Figure 4 shows a bottom view of the PBC.

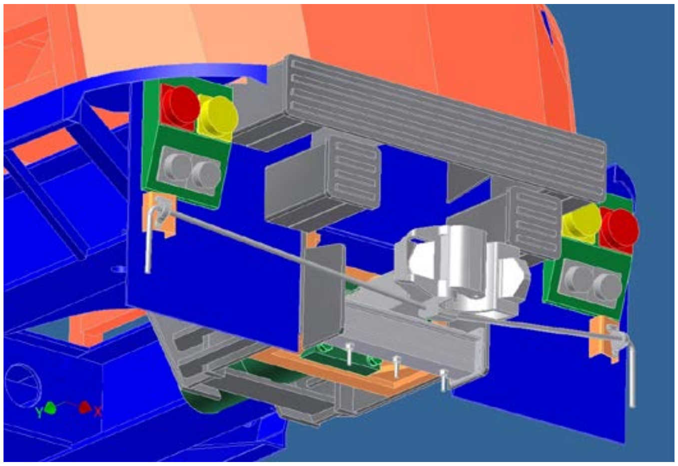

Figure 3. Detailed view of the deformable anti-climber/push-back coupler system retrofit to an MP40 locomotive.

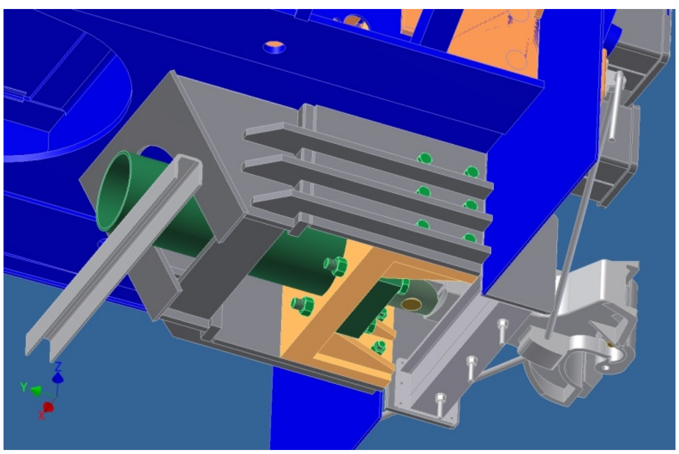

Figure 4. Bottom view of the push-back coupler.

However, in order to demonstrate the feasibility of retrofitting these crashworthy components onto other locomotives, and due to availability of actual vehicles for use in non-destructive and destructive testing, a new research program is currently underway that is developing slightly modified designs of these two locomotive crashworthy components for retrofit onto a General Motors Electro-Motive Division (EMD) F40PH (F40). The EMD F40 is an older locomotive, initially built in 1975. The objective is to modify the designs of both the PBC and the DAC from the MP40 retrofit program, for retrofit to an EMD F40, with as little modification to the structure of the F40 as possible.

Figure 5 shows the forward end of the modified (with CEM) MP40. Slight modifications were made to the MP40 that include support structures added to the underframe for the purpose of transferring impact loads into the underframe. Figure 6 shows the forward end of a conventional F40. It is expected that similar modifications will need to be made to the F40 underframe to accommodate and transfer impact loads.

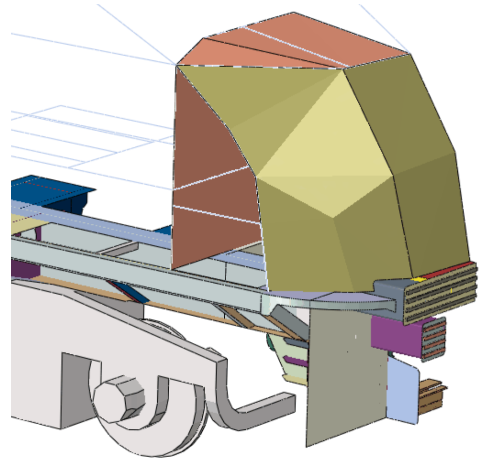

Figure 5. Half-symmetric computer model of forward end of modified MP40 locomotive.

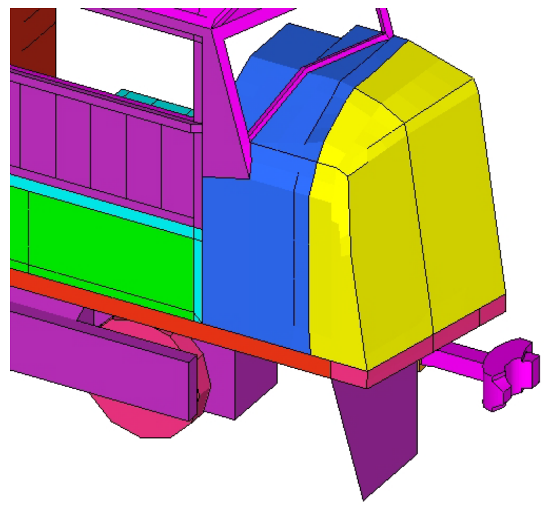

Figure 6. Half-symmetric computer model of forward end of conventional F40 locomotive.

This research program will ultimately integrate the two CEM components onto an F40 locomotive in order to demonstrate that these components work together as in integrated system to mitigate the effects of a collision and prevent override. A series of dynamic PBC coupling tests is planned 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 is important to establish a baseline for conventional coupling to determine the maximum non-destructive conventional coupling speed. Therefore, conventional coupling tests will be conducted first. The first two sets of tests will be conventional and PBC coupling tests, the third set of tests will be vehicle-to-vehicle tests, and the last set of tests will be train-to-train tests.

PLANNED TESTS

Full-scale dynamic tests are planned which will accomplish the objectives of demonstrating that the locomotive crashworthy integrated 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 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 will be coupling tests of a conventional F40 coupling with a Budd M1 cab car (M1). The second set of tests will be coupling tests of an F40 retrofit 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 set of tests are planned to be train-to-train impact tests 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, will demonstrate 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 tests 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
PBC 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 Tests	• Effectiveness of crashworthy components at preventing override • Lateral buckling of coupled cars • Override of colliding cars

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 analyses approaches and models and assure that the factors that influence the response of the equipment are taken into account. Table 1 lists the measurements that are critical in assuring the appropriate modeling and analysis of the equipment.

Conventional Coupling Tests

Before demonstrating the robustness of the push-back coupler, it is important to establish a baseline for conventional coupling to determine the maximum non-destructive conventional coupling speed. Therefore, conventional coupling tests will be conducted first. These tests will establish a baseline for comparison with future CEM coupling tests. The objective of the tests is to measure and characterize the structural performance of the conventional coupler and the coupling vehicles under a range of increasing dynamic coupling speeds until damage occurs in the coupler system. The critical result will be the maximum non-destructive conventional coupling speed. The coupling tests will be conducted repeatedly with the same conventional F40 locomotive and M1 passenger car, starting at 5mph for the first test, and increasing in increments of 2mph until damage occurs in the coupler system (coupler/yoke/draft gear/support structure). A schematic of the test set-up is shown in Figure 7.

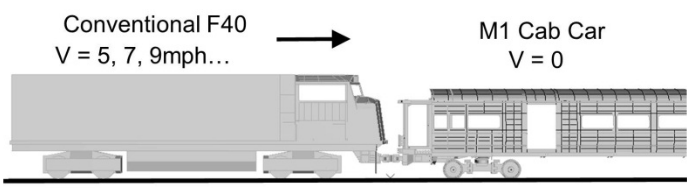

Figure 7. Schematic of conventional F40 coupling tests.

Computer simulations of the impacts will be conducted prior to the tests and will also serve to inform the testing decisions made concerning the conventional coupling tests. The results of the conventional coupling tests will be compared to the analytical predictions and evaluations made on the performance of the equipment.

PBC Coupling Tests

This research program will eventually combine the two CEM components onto an F40 locomotive in order to demonstrate that these components work together to mitigate the effects of a collision and prevent override. However, before demonstrating the performance of the combined components, it is important to demonstrate that the PBC will, or will not, trigger, depending on the proper conditions. Therefore, a PBC will be retrofit to an F40 locomotive and a series of dynamic PBC coupling tests will be conducted. The primary objective is to demonstrate the robustness of the PBC design and determine the impact speed at which PBC triggering occurs. The test objective is to measure and characterize the structural performance of the PBC and the coupling vehicles under a range of increasing dynamic coupling speeds until damage occurs in the coupler system. The PBC coupling tests will be conducted repeatedly with the same PBC-retrofit F40 locomotive and M1 passenger car, starting at 5mph for the first test, and increasing in increments of 2mph until the push-back coupler is triggered. A schematic of the test set-up is shown in Figure 8.

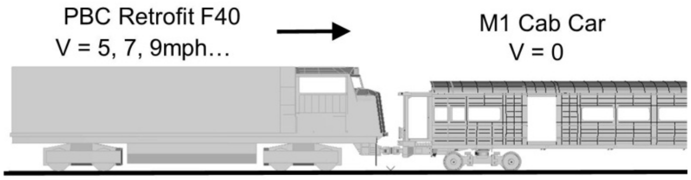

Figure 8. Schematic of PBC-retrofit F40 coupling tests.

The results from the conventional coupling tests will inform the testing decisions made concerning the PBC coupling tests. Computer simulations of the impacts will be conducted prior to the tests and will also serve to inform the testing decisions made concerning the PBC coupling tests. The results of the PBC coupling tests will be compared to the analytical predictions and evaluations made on the performance of the equipment.

Vehicle-To-Vehicle Tests

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 or object, as shown in Figure 9.

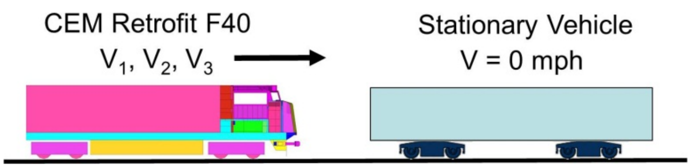

Figure 9. Schematic for vehicle-to-vehicle impact tests.

The objective of these tests is to demonstrate the effectiveness of the PBC and DAC integrated system, and how well they 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 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 details of these tests are currently being analyzed and evaluated. Conducting vehicle-to-vehicle tests with a conventional F40 is also being considered in order to provide a baseline for comparison with the CEM-retrofit F40 vehicle-to-vehicle tests. Table 2 provides the possible vehicle-to-vehicle impact combinations currently under consideration.

Table 2. Vehicle-to-vehicle test options.

Impacting Vehicle	Stationary Object
Conventional F40 Locomotive	M1 Cab Car
	Freight Car
CEM F40 Locomotive: Retrofit with PBC & DAC	M1 Cab Car
	Freight Car
	Conventional F40 Locomotive
	CEM F40 Locomotive
	Tank Car
	Impact Wall

The results from the conventional coupling tests and the PBC coupling tests will inform the testing decisions made concerning the vehicle-to-vehicle tests. Computer simulations of the impacts will be conducted prior to the tests and will also serve to inform the testing decisions made concerning the vehicle-to-vehicle tests. The results of the vehicle-to-vehicle tests will be compared to the analytical predictions and evaluations made on the performance of the equipment.

Train-To-Train Tests

This series of tests will retrofit the CEM integrated system to an F40 locomotive. The CEM-retrofit F40 will then be placed at the front of a freight consist. The CEM consist will then be tested by impacting a stationary conventional consist, as shown in Figure 10. The red oval in Figure 10 indicates CEM equipment located on the front of the first locomotive.

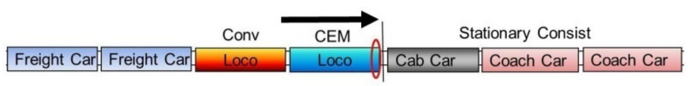

Figure 10. Schematic for train-to-train impact test. Red circle indicates CEM components.

The objective of these tests is to demonstrate the effectiveness of the CEM integrated system in a train-to-train collision. Conducting an additional train-to-train test with two CEM-retrofit F40 locomotives leading the moving consist is also being considered in order to provide a comparison with the single CEM-retrofit F40 train-to-train test. The schematic for this test can be seen Figure 11. Again, the red oval in Figure 11 indicates CEM equipment located on the front of both locomotives. The progression of tests from one CEM-retrofit locomotive to two is intended to show an incremental improvement of locomotive crashworthiness, with increasing amounts of CEM components retrofit to the equipment resulting in increased crashworthiness. As it is very early in the planning stage for these tests, the details are currently being analyzed and evaluated.

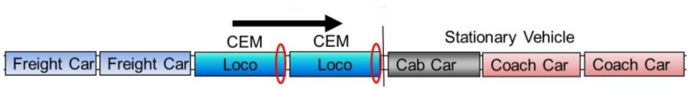

Figure 11. Schematic for possible additional train-to-train impact test options. Red circle indicates CEM components.

TEST REQUIREMENTS

Requirements for the conventional coupling tests include the specification of the equipment to be tested, the conditions for the test, and the information to be gathered during the test. Pre-test simulations will be conducted to bound the range of potential responses of the equipment. The results of the simulations will be used to determine critical measurements, and the sizing and placement of instrumentation. The requirements for PBC coupling tests will be developed from simulations, as well as the experience gained in performing the conventional coupling tests. Similarly, the requirements for the vehicle-to- vehicle tests will be developed from simulations, as well as the experience gained in performing both sets of conventional coupling tests. Lastly, the requirements for the train-to-train tests will be developed from simulations, as well as the experience gained in performing both sets of conventional coupling tests and the vehicle-to-vehicle tests.

Conventional Coupling Tests Requirements

The equipment that will be used for the conventional coupling test will be a conventional F40 locomotive and an M1 passenger cab car. The F40 has been modified for S-580 compliance [7]. F40 locomotive #234 will be used in the tests and can be seen in Figure 12. A close-up of the front end structure of F40 #234 can be seen in Figure 13.

Figure 12. F40 locomotive #234 will be used in the conventional coupling tests.

A photograph of the M1 cab car that might be used in the conventional coupling tests is shown in Figure 14, with a closer view of its coupler and surrounding structure shown in Figure 15. As can be seen in the two photographs, this M1 cab car (#9324) exhibits damage from a small fire. The structural elements of the end frame appear to be unharmed and intact and the rest of the vehicle is undamaged.

Figure 13. Front end structure of F40 #234.

Figure 14. M1 cab car #9324 with some fire damage.

Figure 15. M1 cab car #9324 coupler and surrounding structure.

For the conventional coupling tests, the locomotive will impact the stationary M1 at increasing dynamic coupling speeds until damage occurs. The coupling tests will be conducted repeatedly with the same conventional F40 locomotive and M1 passenger car, starting at 5mph for the first test, and increasing in increments of 2mph until damage occurs in either the locomotive coupler system or M1 coupler system (coupler/yoke/draft gear/support structure).

The information desired from the conventional coupling tests includes the longitudinal, vertical and lateral accelerations and displacements of the couplers, the coupler supporting structures, the vehicles, and the trucks. Of particular importance is determining the maximum non-destructive coupling speed between the two vehicles and their couplers. Extreme care will be taken to inspect the equipment and all components after each coupling test to ascertain the condition of the equipment and determine if any damage has occurred.

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

PBC Coupling Tests Requirements

Requirements for the equipment tested in the PBC coupling tests will be the same as in the conventional coupling tests, with the addition of the retrofit of the PBC onto the end frame of the locomotive. The equipment that will be used for the PBC coupling test will be a PBC-retrofit F40 locomotive and an M1 passenger cab car. It is hoped that the same F40 used in the conventional coupling tests, F40 locomotive #234 shown in Figure 12, will be undamaged and can therefore be retrofit with a PBC. A close-up of the front end structure of F40 #234 can be seen in Figure 13.

While research is currently being conducted to design the retrofit of the PBC to an F40, Figure 16 shows the test fixture for a PBC designed for retrofit to an MP40 locomotive. Figure 4 shows a bottom view of this design.

Figure 16. Push-back coupler (PBC) test fixture, designed for retrofit to an MP40 locomotive.

This full-scale test fixture was fabricated and impact tested successfully, demonstrating the effectiveness of the design. The test results were in very good agreement with simulation predictions in terms of force-displacement behavior. The design of the PBC retrofit for the F40 locomotive will be very similar to this design for the MP40.

For the PBC coupling tests, the PBC-retrofit locomotive will impact the stationary M1 at increasing dynamic coupling speeds until the PBC triggers. The coupling tests will be conducted repeatedly with the same PBC-retrofit F40 locomotive and M1 passenger car, starting at 5mph for the first test, and increasing in increments of 2mph until the PBC triggers.

The information desired from the PBC coupling tests includes the longitudinal, vertical and lateral accelerations and displacements of the couplers, the coupler supporting structures, the vehicles, and the trucks. Strain gages will be placed on the PBC, the locomotive carbody, as well as on the M1 carbody to determine the local deformations and measure the load paths resulting from the coupling impacts.

Of particular importance is determining the maximum non-trigger coupling speed between the two vehicles and their couplers. Extreme care will be taken to inspect the equipment and all components after each coupling test to ascertain the condition of the equipment and determine if any damage has occurred.

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

Vehicle-To-Vehicle Tests Requirements

The equipment requirements for the vehicle-to-vehicle tests will be the same as in the PBC coupling tests, with the addition of the retrofit of the CEM integrated system (PBC and DAC) onto the end frame of the locomotive. The equipment that will be used for the vehicle-to-vehicle test will be a CEM-retrofit F40 locomotive and an M1 passenger cab car. It is hoped that the same F40 used in the conventional coupling tests and the PBC coupling tests, F40 locomotive #234 shown in Figure 12, will be undamaged and can therefore be retrofit with a DAC to complete the CEM system on the locomotive. As a point of reference, Figure 17 shows the test fixture for a DAC designed for retrofit to an MP40 locomotive. This full-scale test fixture was fabricated and impact tested successfully, demonstrating the effectiveness of the design. The test results were in very good agreement with simulation predictions in terms of force-displacement behavior and modes of deformation. Research is currently being conducted to design the retrofit of the DAC to an F40, which will be very similar to this design for the MP40.

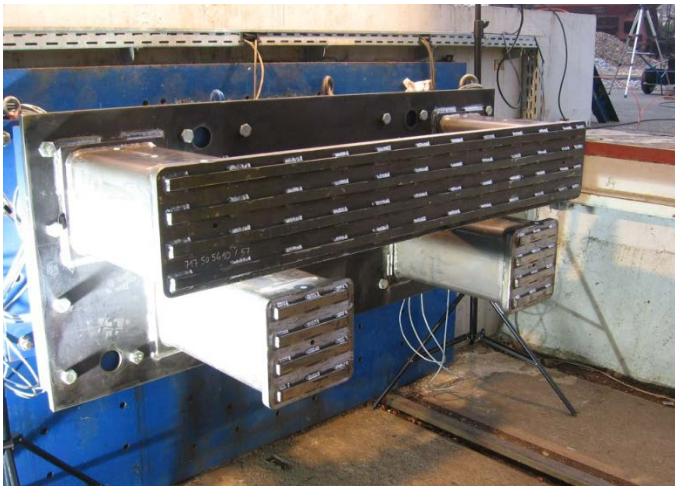

Figure 17. Deformable anti-climber (DAC) test fixture, designed for retrofit onto an MP40 locomotive.

For the vehicle-to-vehicle tests, the CEM-retrofit locomotive will impact the stationary M1 with enough speed to trigger the PBC, exhaust the PBC, and then deform the DAC as much as possible. The objective is to absorb all of the impact energy without override, and without damaging the supporting structure of the locomotive or imparting significatn damage to the stationary vehicle. Another objective is to be able to demonstrate the reparability of the CEM components by replacing the damaged parts, installing new crashworthy components, and running another vehicle-to-vehicle impact test. Conducting vehicle-to-vehicle tests with a conventional F40 is also being considered in order to provide a baseline for comparison with the CEM-retrofit F40 vehicle-to-vehicle tests. Table 2 provides the possible vehicle-to-vehicle impact combinations currently being considered.

The information desired from the vehicle-to-vehicle tests include:

- the longitudinal force acting on the couplers and the DAC,
- the longitudinal, lateral, and vertical displacements of the couplers and the DAC, and
- the gross motions of the vehicles relative to each other.

Strain gages will be placed on the CEM components, the locomotive carbody, as well as on the M1 carbody to determine the local deformations and measure the load paths resulting from the coupling impacts.

The force-crush characteristic is a key characteristic of the couplers and the cars. One purpose of these tests is to take measurements for comparison with analytical predictions in order to validate that such predictions are accurate.

As it is very early in the planning stage for these tests, the details are currently being analyzed and evaluated.

Train-To-Train Tests Requirements

The equipment requirements for the train-to-train tests will be the same as in the vehicle-to-vehicle tests. However, rather than having just a CEM-retrofit locomotive impacting a stationary vehicle, a CEM-retrofit locomotive-led consist will impact a stationary conventional consist. The equipment that will be used for the train-to-train tests will be a CEM-retrofit F40 locomotive and an M1 passenger cab car. The trailing cars of the consists will likely be freight cars for the locomotive, and passenger cars for the cab car.

If the same F40 used in all of the previous tests, F40 locomotive #234 shown in Figure 12, is still undamaged, it may be used again for these tests. The objective of these tests is to demonstrate the effectiveness of the CEM system in a train-to-train collision. This will be demonstrated if all of the impact energy is absorbed without override, and without damaging the supporting structure of any of the vehicles in either consist. Another objective is to be able to demonstrate the incremental increase in crashworthiness by running another train-to-train impact test with two CEM-retrofit locomotives at the front of the moving consist.

The information desired from the vehicle-to-vehicle tests include:

- the longitudinal, lateral, and vertical forces at the colliding interface, and
- the gross motions of the colliding vehicles relative to each other.

Strain gages will be placed on the CEM components, the locomotive carbody, as well as on the M1 carbody to determine the local deformations and measure the load paths resulting from the coupling impacts.

As it is very early in the planning stage for these tests, the details are currently being analyzed and evaluated.

TEST IMPLEMENTATION

The test implementation consists of the equipment test, the instrumentation, the data acquisition, and the test procedures. The tests will very likely all be conducted at the Transportation Technology Center, Inc. (TTCI) located in Pueblo, Colorado.

As stated previously, due to the nature of the design of both the PBC and DAC, it is hoped that the same F40 locomotive #234 can be used for the conventional coupling tests, the PBC coupling tests, as well as all of the subsequent tests involving a CEM-retrofit locomotive. If irreparable damage occurs to F40 #234, another locomotive, also S-580 compliant, will be used. Similarly, it is hoped that the same M1 cab car can be used for all of the tests. However, if irreparable damage does occur, another M1 will be used.

Accelerometers, strain gages, string potentiometers, high-speed digital cameras, and digital cameras will be used to gather data during the tests. A data acquisition system, likely on-board the vehicles, will be used to record the measurements from the instrumentation. Battery-powered data bricks will be used to provide the necessary number of data channels for each test.

Speed calibration tests will be carried out on a parallel track. In these speed calibration tests, the impacting vehicle/train will be released at a particular point, and the speed of the vehicle is measured as it passes the impact point. Once several speed calibration tests have been carried out at various release points, the release point for a particular speed can be calculated. The factors that affect the release distance are the rolling resistance of the vehicle on the track, the bearing resistance, the aerodynamic drag of the vehicle, and the gradient of the track. All of these factors are accounted for in the speed calibration tests.

SUMMARY

Locomotive crashworthiness research is being conducted to evaluate and test new technologies for increasing the safety of passengers and operators in rail equipment. 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. Two locomotive crashworthy components, a PBC and a DAC, have been developed that inhibit override in the event of collision. Prototypes of these two components have been fabricated and dynamically tested individually with successful results. The objectives of the locomotive crashworthiness research program are to demonstrate that the locomotive crashworthy integrated system performs well in service, provides crashworthiness compatibility with a range of equipment, and exhibits increased crashworthiness over conventional equipment. A testing program is planned that will ensure that these objectives will be met. The coupling tests will demonstrate that the PBC performs as expected in service. The vehicle-to-vehicle tests will show the integrated system's compatibility with a range of equipment. The train-to-train tests will exhibit the integrated system's increased crashworthiness over conventional equipment.

Efforts are underway to prepare for the first series of tests, the conventional coupling tests. Simultaneously, the designs for the PBC and DAC are currently being modified and analyzed for retrofit to an F40 locomotive.

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