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Railroad Freight Car Remote Controlled Electrically Driven Set & Release Hand Brake (EDHB) – Wireless Control Development

DOT/FRA/ORD-21/26

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NOTICE

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14. ABSTRACT
This report discusses the development of prototype Electrically Driven Hand Brakes (EDHB) that provide remote automatic set and release functions from push buttons mounted on the side of a car, or wirelessly. The EDHB improves the safety of railroad operations in several ways, including making it easier to ensure that freight cars are parked effectively; additionally, it has the potential to eliminate injury and fatality risks for railroad employees having to get between cars, climb ladders, and physically operate hand brakes. Previously, a prototype EDHB was designed and lab and field verified for functionality and a specification was drafted that is under Association of American Railroads' (AAR) review for use by the industry when designing and implementing remotely controlled hand brakes. After further development, that included increasing the efficiency of the drive train, improving the efficacy of the motor's power, improving the control system, and the development of a more positive feedback system to ensure the appropriate torque is applied to the hand wheel drive shaft to meet hand brake application input specifications. This report covers the development of the new controller to include wireless communications and control, and the testing of such work.

15. SUBJECT TERMS
Electrically Driven Hand Brake, EDHB, remote control, release sensor, electro-pneumatic, application sensor, vertical wheel, Group N, Group O, specification, standard, performance, wireless communication, control, rolling stock, brakes, car

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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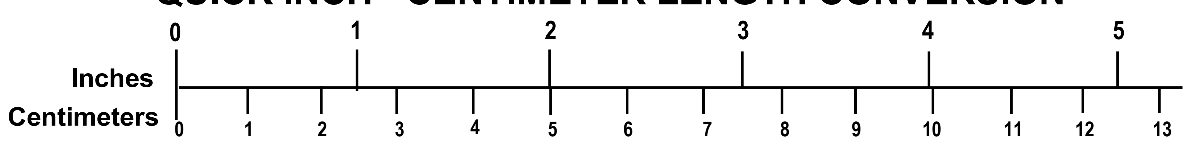
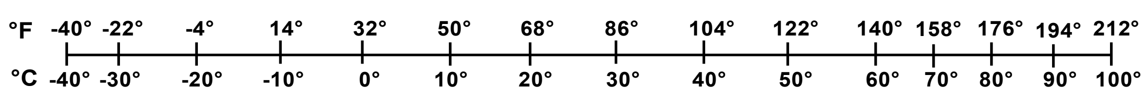
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

As part of a prior project, the Federal Railroad Administration's Office of Research, Development and Technology developed prototype Electrically Driven Set & Release Hand Brakes (EDHB), with Sharma & Associates, Inc. (SA), that were successfully engineered and tested for freight car use. The consensus was to continue to improve the EDHB design after passing a set of in-lab and field performance requirements laid out by the Association of American Railroads' (AAR) Geared Hand Brake Mechanical Engineering Committee (GHBMEC), its Remote Operation Hand Brake (ROB) task force, and SA.

Subsequently, the work focused on the improvement of the EDHB controls, feedback and drive-train efficiency, thereby, effectively enhancing the brake's efficiency, accuracy, and reliability. Testing and demonstrations verified the enhancements.

This report covers the latest step in the development of the EDHB: the design and test of a wireless communications and control system prototype for the EDHB. This work was accomplished from October 2017 through October 2019, it included the addition of a wireless module on the control board, and short and longer simulated train field testing.

Freight railroads have continually worked to potentially eliminate train crew injuries that occur during the process of applying and releasing freight car hand brakes. Still, currently, a person must crank a handle or turn a wheel at awkward positions to get a hand brake to set at the appropriate chain load; approximately 138 pounds applied at the hand brake wheel. This often leads to back injuries or trips/falls. If the operator slips or a brake mechanism fails to engage, injuries can occur. Also, there are inherent safety issues with the physical climbing of ladders to operate the brakes and the need to occasionally go in between cars to access the brakes. Releasing hand brakes sometimes also causes injuries due to many of the same reasons as those that cause injuries when applying a hand brake. The goal is to develop a hand brake that requires minimal effort by a human to operate, it has the potential to eliminate the need to climb up ladders and get between cars, and improves the likelihood of hand brakes being applied and released when needed.

Additionally, past tragic events—as in the event at Lac Megantic—have highlighted the need for ensuring that a sufficient number of hand brakes are fully applied on any parked train to decrease the potential for 'runaway' trains. The use of systems where hand brakes can be applied from the side of the car by 'push button' rather than by strenuous human physical effort, especially at the end of a long shift, makes a big difference in ensuring that trains are safely secured when parked.

Further, SA designed the EDHB to impart controlled application and release input forces which will reduce equipment damage; the design includes clearer feedback about the status of the hand brake that will improve safety in operations, and ensure reduced wheel set and track damage normally caused by unreleased hand brakes upon train movement.

The main challenge to the deployment of any electrically driven set and release type hand brake has been the lack of electrical power on freight cars that can be used to operate a motor to apply the hand brake. Things are starting to change in that regard. Currently, Electronically Controlled Pneumatic (ECP) train line brakes are being utilized in the industry. Also, a parallel power line that uses electrical power from locomotives is being developed and may be implemented on

freight cars. Finally, the design of the EDHB is power efficient and estimated to operate with one set of two 12 VDC batteries, with no supplemental charging, for over a year.

Supplemental wireless communications and control was designed, implemented and tested as part of the EDHB design; this supplemental improvement, although in the prototype stage, takes the EDHB yet another step closer to industry acceptance and implementation.

1. Introduction

Previously, Sharma & Associates, Inc. (SA) and the Federal Railroad Administration's (FRA) Office of Research, Development and Technology developed prototype Electrically Driven Set & Release Hand Brakes (EDHB) that were engineered and tested for freight car use. After successfully passing a set of lab and field performance requirements laid out by SA, the Association of American Railroads' (AAR) Geared Hand Brake Mechanical Engineering Committee (GHBMEC), and the Remote Operation Hand Brake (ROB) task force, FRA decided to further optimize the prototype design to improve control and feedback, the mechanical design efficiency, and to improve application and release times; which effectively enhanced the reliability and safety offered by EDHB. Therefore, SA implemented improvements to the communications, control, feedback, and mechanical design of the EDHB and verified it through rigorous testing. This previous work and a draft specification for AAR approval were accomplished under research efforts conducted from 2008 through 2017, while this work was accomplished from 2017 to 2019.

1.1 Background

For years, freight railroads have been attempting to potentially eliminate train crew injuries that occur during the process of applying and releasing freight car hand brakes. Currently, a person must crank a handle or turn a wheel in awkward positions to set hand brakes to the appropriate chain load (i.e., approxamately138 lbs. applied at the hand brake wheel). This often leads to back injuries or slips, trips or falls. If the operator slips or the brake's mechanisms fail to engage, injuries occur. Also, there are inherent safety issues with the physical climbing of ladders to operate the brakes and the need to occasionally go in between cars to access the brakes. Releasing hand brakes sometimes also causes injuries due to many of the same reasons as those that cause injuries when applying a hand brake. The goal is to develop a hand brake that requires minimal effort by a human to operate, has the potential to eliminate the need to climb up ladders and get between cars, and improves the likelihood of hand brakes being applied and released when needed.

A critical safety issue related to hand brakes was highlighted by the tragic events at Lac-Megantic: that is the need to ensure that a sufficient number of hand brakes are fully applied on any parked train to decrease the potential for 'runaway' trains. The use of systems where the hand brakes can be applied from the side of the car by 'push button,' or wirelessly, rather than by extreme physical effort, especially at the end of a long shift, would make a big difference in ensuring that trains are safely parked.

Along with the improved safety, an electrically driven, remotely controlled hand brake provides better control to ensure the correct amount of shoe force at the wheel. Today, hand brakes are applied by human force to varying degrees because there is no indicator that tells the crewmember whether a brake is fully applied or not. Further, controlled application and release forces will reduce equipment damage and applied and released feedback will ensure safety during application and reduce wheel set and track damage due to unreleased hand brakes upon train movement. Hand brakes, unfortunately, are often unintentionally left applied during car movement for various reasons. These unreleased hand brakes result in slid flats or otherwise damaged wheels which in turn increase stress on rolling stock, track, and lading.

One of the main challenges to the deployment of any electrically driven set and release type hand bake or other electrically powered devices has been the lack of electrical power on freight cars. Currently, a power line is being developed and could be implemented on freight cars as a battery charging source. With such electrical power on board, a whole new realm of possibilities for new technology implementation exists, such as an EDHB. It should be noted that the EDHB has shown that it can operate for at least a year on one set of 12-VDC batteries even without a battery charging source being implemented.

This report discusses the latest work on the EDHB: the design, development and testing of a wireless communications and control system prototype. Considering the current development of wireless technologies, it makes sense to supplement EDHB operations with an option for wireless control. A prototype wireless control system was developed for test and demonstration in the application, release, and status checks of multiple EDHBs along both: 1) a 5 vehicle consist and 2) a 150-car train. Figure 1 shows an EDHB under test at TTCI.

Figure 1. An SA designed and developed EDHB under test at Transportation Technology Center, Inc. (TTCI)

1.2 Objectives

The development of the EDHB system was done to improve the safety and reliability of freight railroad switching operations. The main objectives of this project were to further develop the EDHB to include a wireless interface and control system. Previous work included the development of a performance specification with which the industry can develop EDHB-like equipment. In this regard, safety standards and recommended practices will be affected going forward as the effects of new equipment will exist in future service. The objectives were accomplished by executing the following tasks:

Task 1

The development of the system architecture considered the best wireless technology for control of EDHB; at the same time, SA built and installed EDHB's on four cars and installed the control interface on a locomotive at the Transportation Technology Center (TTC) in Pueblo, CO.

Task 2

SA developed the EDHB wireless control test plan for the locomotive and a four rail car consist and conducted testing of wireless control of EDHB; this was accomplished by demonstrating how the locomotive interface displays the status of a particular EDHB and the ability to apply and release all four EDHBs from the locomotive cab.

Task 3

SA reviewed the results from Task 2 and scaled the test setup for the Task 4 work of testing and demonstrating the wireless communications and control on a much longer simulated train.

Task 4

SA developed a test plan that included the physical simulation of a 150-car length of wirelessly controlled EDHBs. Then SA conducted testing of the prototype communication and control system to demonstrate the ability to wirelessly communicate status, and control application and release of 4 EDHBs located at distances along a simulated train of up to 150 rail cars of equivalent length.

This document serves as the final report on the development of a prototype wireless communications and control system for EDHB.

1.3 Overall Approach

There is a need for easily applied and released hand brakes, with crew feedback, on freight cars. The design approach for EDHB addresses that need while keeping the AAR specified functions and minimizing costs. Currently, it makes sense to develop a wireless communications and control option. The need stems from safety issues related to hand brake and railroad operations. The wireless capability would allow for easier installation of communications and controls, and benefit crew knowledge of the status of each hand brake.

The research began with a technology survey of wireless options. It then continued with the concept development and prototype build. Finally, researchers tested it at different distances on full scale railcars at the TTC, in Pueblo, CO.

1.4 Scope

The scope included the research into and selection of a feasible wireless technology, the build and adaptation of the technology to the EDHB controller, and the testing of such on full-scale cars at varying distances.

1.5 Organization of the Report

The details of the work performed are outlined in the following sections:

Section 2 provides the details of the EDHB design features.

Section 3 describes the actions and design changes performed on the EDHB to allow for wireless control.

Section 4 outlines the two-phase testing performed to analyze the new EDHB wireless interface and control design.

Section 5 describes the results from the EDHB wireless controls testing.

Section 6 summarizes the work performed and information regarding additional testing.

2. Initial Design Features

The following are design features of the EDHB.

2.1 Proven Core (Base Hand Brake)

The EDHB design began by selecting an existing AAR Group N vertical wheel hand brake to serve as the core of the EDHB system. One requirement for the selection was that it would be more suitable if the hand brake had an extended history of successful operations in interchange service and, moreover, was AAR inter-change compliant. Several commercially available hand brake designs have long and successful histories. One of them, Cardwell Westinghouse's U-9300 from their Universal brand was selected for this effort as it was a good representative. Thorough knowledge of the design and functionality were critical in the design of the EDHB system, and allowed for successful retrofit, see Figure 2, without adversely affecting its core performance.

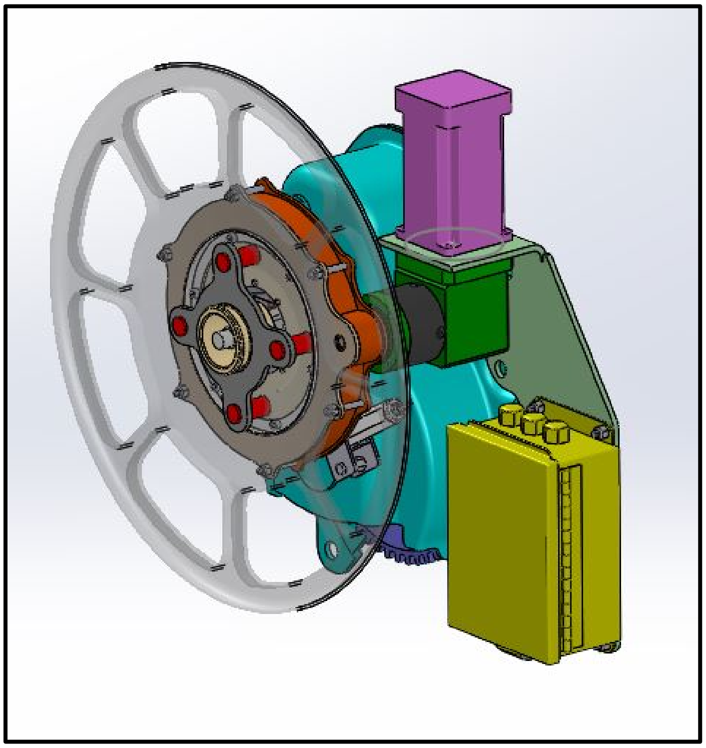

Figure 2. EDHB retrofitted components

2.1.1 Manual Operations

One key to the success of the EDHB design is the ability to disengage the remote controlled, electrically driven part of the system, allowing the hand brake to be used as a normal, conventional hand brake. This was the first decision made in the design and development of this system. With this capability, the risks of implementing the EDHB system are minimized because the hand brake remains fully functional even if there is a failure in the electrical system or EDHB retrofit. Thus, the advantages gained by EDHB implementation far outweigh the risks.

2.1.2 AAR Compliance

Because the EDHB design began with an existing hand brake that underwent and passed AAR certification testing, the only concerns regarding final AAR certification are the modifications and additions required for the added EDHB functionality.

Existing AAR standards do not include a specification for advanced hand brake designs that are remotely controlled and electrically actuated. Therefore, no existing specifications constrained the functional aspects of development. However, existing specifications do constrain some physical properties of the hand brake. All specifications regarding physical constraints for Conventional Group N and Intermediate Group O hand brakes in the AAR Manual of Standards and Recommended Practices, including overall depth, clearance between the rim of the wheel and any part of the housing, and mounting-hole locations, were adhered to in the EDHB design.

2.1.3 Electrical Power

The existing freight railroad infrastructure does not have any provisions for electrical power on freight cars. The EDHB system was developed with a focus on this limitation. The EDHB is currently designed to operate off a 24 VDC power source, which is a voltage commonly used in industrial control systems. At the time of the design, this allowed for a wider selection of commercially available equipment to power the system.

Also, due to the lack of an existing electrical power infrastructure, the system design incorporates features to conserve the amount of energy consumed, which allows the system to be powered for extended periods using only batteries. Hand brakes require a considerable amount of power to both apply and release. However, hand brakes are typically not used frequently. Assuming a hand brake goes through a complete application-release cycle every 3 days and the total cycle time is 3.2 minutes, the duty cycle is 0.07 percent. Due to the low duty cycle the average power required is only a fraction of the peak power requirement. The controller design minimizes idle energy consumption by either disabling or removing supply power from non-essential circuits. Additionally, the microcontroller is placed in sleep mode and is only activated upon receiving a command from the operator control station. Considering the duty cycle, engineering calculations indicate that idle periods are responsible for less than 2 percent of the total energy consumption, while the application and release cycles are responsible for over 98 percent due to the high power required for operation.

The feedback indicators incorporated into the design are all light-emitting diode (LED) based to further conserve energy. Additionally, the indicators provide active feedback only when the system is active and for a couple of seconds following the completion of an operation. The current state of the hand brake at any moment in time is seen by activating the indicators on any of the control interfaces, at which point they will remain active for only a few seconds before deactivating once again. An additional benefit of utilizing LED technology for the indicators is the extended life and reduced maintenance compared with using incandescent indicators.

The power control features engineered into the design allow the system to be operated from battery power for extended periods, without intervention. Engineering estimates based on the above duty cycle assumption, theoretical power consumptions, and battery specifications show that the system can be powered by two 100 Ah capacity 12 V SLA batteries wired in series to provide 24 V to the system for a period of over 400 days. Because of the efficiency of the EDHB system design, the natural self-discharge of the batteries is a significant factor in battery life, contributing to over 42 percent of the overall battery drain.

2.1.4 Interface

The operator interface is one of the key components of the EDHB system. Through the operator interface, personnel can quickly determine the status of the hand brake on EDHB equipped cars. Additionally, the feedback indications provided by the EDHB system through the operator interface are a more reliable indication of the hand brake status than observation of the chain tension or ‘feeling’ the torque that is applied or required to further turn the hand wheel. The ability to quickly and accurately determine the status of a hand brake can make operations safer and more cost effective by reducing the number of incorrectly applied and/or released hand brakes during operations. See Figure 3 as an example of the operator interface.

Figure 3. Example of operator interface

The EDHB controller is designed with simple discrete digital interface capabilities. This allows the system to be used with operator interfaces ranging from simple pushbutton enclosures mounted on the car sides to computer-based interfaces mounted in a locomotive cab.

The controller includes three discrete inputs for controlling the system, one for starting a hand brake application cycle, one for starting a hand brake release cycle, and one for showing the status of the hand brake. The three inputs can be electrically configured as either sinking or sourcing. This allows the flexibility to interface with most common 24 volt signaling systems, in addition to dry contacts.

Four discrete outputs are included to provide feedback of the system status to the operator. Indications are provided for Hand Brake Applied, Hand Brake Released, System Active, and System Error. The circuitry for these outputs is 24 VDC and can be configured as either sinking or sourcing.

Any control system capable of interfacing with 24 VDC discrete signals can be used to control the EDHB system. This includes control systems that include wireless Input/Output (I/O) capabilities where, for example, an interface can be located in a locomotive cab and a remote I/O block can be located near the EDHB system allowing an operator in the locomotive cab to both monitor and control the EDHB system without leaving the cab.

2.1.5 Wireless Concept

Through previous funding, and FRA guidance, the SA team developed the prototype EDHB system and has successfully validated the design through various testing and demonstrations. Figure 4 shows the EDHB wirelessly controlled via an off-the-shelf communications method.

Figure 4. Previous wireless demo of EDHB

2.2 Current Design Features

2.2.1 Improved Drive Train

Continuing work on the EDHB system showed that the original gearbox design was not operating at an efficiency level comparable to manufactured gearboxes. To further improve the accuracy of the system and improve the torque transfer capability of the gearbox the design was modified to use a commercially available gearbox in place of the original. Figure 5 shows the redesigned system. Further testing confirmed the anticipated benefits of the redesign.

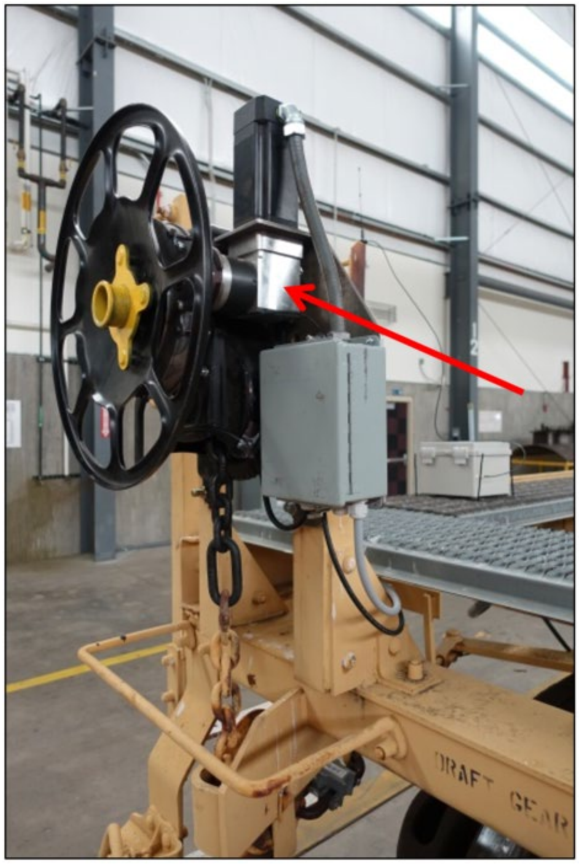

Figure 5. New gearbox installed in system

2.2.2 Improved Feedback

In addition to the potential improvements identified in the gearbox efficiency, researchers determined that the hand brake status feedback system could be improved through the addition of a strain sensor on the brake housing. Stress analysis was carried out on the hand brake housing which allowed for the appropriate selection of locations for application of the feedback sensor (s). Changes to accommodate the new sensor were incorporated into the new controller. Figure 6 shows one location that the feedback sensor was applied for use in establishing hand brake driveshaft input control through communications with the motor.

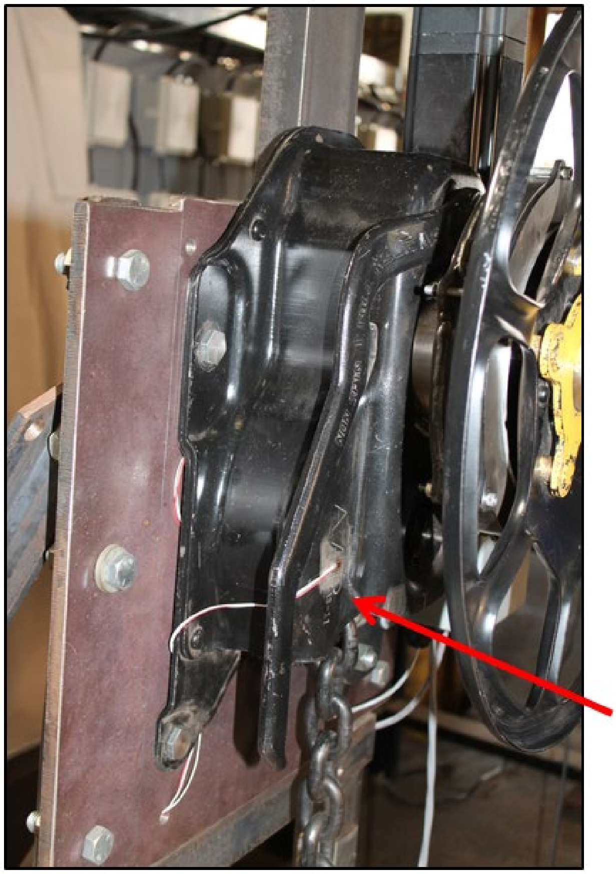

Figure 6. Strain gage mounted on hand brake (not necessarily actual application location)

Testing of the new design shows that the feedback from the active monitoring results in hand brake drive shaft input loads and application chain loads that are much more consistent between cycles. This design provides a higher degree of confidence over the previous design because the hand wheel torque is applied more appropriately and consistently.

2.2.3 Improved Control/Timing System

Timing irregularities were identified during testing of previous designs that sometimes resulted in resonant vibrations that occasionally resulted in improper brake applications and releases. Potentially, this issue was eliminated in the redesigned controller by offloading the motor timing from the microcontroller to a dedicated integrated circuit.

Testing of the new system shows improvements in motor stability and torque, as well as a significant reduction of resonance induced drive vibrations. Additionally, the change in control and timing improved the application and release times for the hand brake from approximately 130 seconds to 100 seconds per function.

2.2.4 Increased Motor Voltage Supply Capability

In an effort to make the system as capable as possible, a new driver was designed in parallel with the new controller to be able to use higher voltages to drive the motor. Higher voltages will allow the motor to produce more torque which may make it possible in the future to reduce the size of the motor and/or reduce the time required for brake application and release.

Testing of the system showed that the combination of design improvements resulted in a system that could operate effectively using the original design supply voltage of 24 VDC, without a strict requirement to utilize a higher voltage. Time constraints prohibited further testing with higher voltages to confirm the expected benefits of the new drive design.

3. EDHB Wireless Interface Development & Design

This section describes the actions and design changes performed on the EDHB to allow for wireless control.

3.1 Hardware Modifications

As the controller was redesigned for additional functionality and improvement as described previously, the interface signaling of the controller was modified. Additional input and output interfaces were included in the redesigned controller specifically for interfacing it with systems external to the EDHB system. Further to the additional interfaces, the existing control station interfaces were simplified to reduce the component count of the controller which provides advantages in both cost and reliability.

3.2 Firmware Modifications

The new interfaces required the addition of firmware code to activate functionality. While the overall functionality of the new interfaces parallels the existing control station interfaces, there are some important differences that required efforts beyond simply duplicating the existing code for additional inputs and outputs.

As mentioned previously, the system status outputs are deactivated shortly following a cycle completion to reduce power consumption and extend battery life. While this accomplishes the intended goal, it significantly complicates interfacing the EDHB to external systems because the status signals would only be valid when the controller was active. The controller redesign includes latching relays that provide maintained signals to external devices even when the EDHB controller is sleeping. By utilizing latching relays, the control code is slightly more complex. However, the signals can be maintained at all times without requiring any electrical power during periods of inactivity which significantly simplifies interfacing the controller to external equipment.

3.3 Additional Hardware

Several additional pieces of hardware are required for the ability to control the EDHB system wirelessly from a remote station.

First, each car with an EDHB system requires a wireless remote I/O module. This module provides discrete inputs and outputs that can be read and controlled via the wireless network interface. The inputs and outputs are connected to the external interface outputs and inputs of the EDHB controller, respectively.

Because a wireless remote I/O module meeting the requirements of this implementation was not readily identified, this functionality was split between two pieces of hardware, a wired remote I/O module and a wireless gateway. These two devices are connected via wired Ethernet to provide the functionality required for the system.

In addition to the hardware required on the cars, hardware is required for the Human Machine Interface (HMI) station, which is located at the locomotive. Similar to the hardware configuration on each car, the locomotive is configured with a touch-screen HMI which is connected via wired Ethernet to a wireless gateway.

3.4 Communication Protocols

The core communication of the system is Ethernet based and includes both wired and wireless implementations. As mentioned previously, some of the hardware components communicate between each other via wired Ethernet. Most of the system communication is handled wirelessly with an IEEE 802.11s-based wireless mesh implementation. Using this standard, each node can be both a communication endpoint/gateway and a relay, thus, the locomotive station should not be able to communicate directly with all car nodes of the train. When nodes are unreachable via direct paths, intermediate nodes can efficiently relay the message appropriately such that it reaches its intended destination node.

At the higher levels of the communication stack, the system devices utilize the Modbus/TCP communication protocol. The Modbus suite of protocols is mature, widely deployed, highly understood, and well suited for use in remote I/O communication systems.

3.5 HMI Design

The HMI utilized is a typical commercially available touchscreen-based unit. The HMI is configured as the Modbus system driver and initiates all system communications. Each car is configured as a Modbus system follower and only initiates actions and provides feedback at the request of the system Master at the locomotive.

The look of the HMI screens is fully configurable, but for this test, one screen was created for each car in the consist as well as an overall consist view. The consist view screen allows for the operator to initiate hand brake application or release on the entire consist with the selection of a single control on the screen. The individual screens for each car allow for the activation of brake application or release for that individual car along with showing the current status of the hand brake on that car.

4. Wireless Control Test Procedure

This section outlines the testing performed to analyze the new EDHB wireless interface and control design. Testing was conducted in two phases: controlling EDHBs on a consist of four rail cars (i.e., each equipped with an EDHB) and a locomotive; and using the same locomotive and four rail cars equipped with EDHBs to simulate a 150-car length consist.

4.1 General Test Equipment and Location

Researchers conducted all testing at the Transportation Technology Center in Pueblo, CO.

The installation of the latest generation of EDHBs occurred on the following test cars:

- UTLX96420 (tank car)
- DTTX454012 (well car)
- UP44113 (hopper)
- UP72053 (covered hopper)

SA provided the control console, wireless control equipment, and all required cabling.

The test demonstration was recorded using video and still-frame cameras.

Power to the control console was supplied from different sources for each test. The Passenger Services Building wall power was used during the short train test. Then at the beginning of the long train test, an inverter was used via a convenience receptacle in a TTC service truck; a decision was then made to replace the electrically noisy inverter with a service truck mounted generator for use during the long train testing. There was a concern that the electrically noisy inverter might interfere with communications.

Power was supplied to the EDHBs and associated wireless equipment by sealed lead-acid batteries located on each test car.

4.2 Short Train Test

Phase I testing was conducted with the test subjects positioned with approximately 10 feet between each other in a four-car consist and in the Passenger Services Building (PSB) at TTCI.

The consist was appropriately secured with wheel chocks on each car to prevent motion when the hand brakes are released.

The control console was located trackside approximately 4 feet above ground level at a position approximating the location of the cab of a connected locomotive. Power was supplied to the control console via a standard 120 VAC electrical receptacle in the building.

The short train test was performed following a previously approved test plan. Figure 7 shows a photo of the EDHB system, including the control box, being installed on the covered hopper.

Figure 7. EDHB installation on the covered hopper prior to short train test

4.3 Long Train Test

Testing was conducted with the four test subjects installed on cars that are separated by several determined distances to demonstrate long-train EDHB wireless control.

Testing was executed outdoors on a tangent section of the Precision Test Track (PTT) track with a low grade at the test location. The locomotive was placed near the north side of the passenger vehicle overpass on the PTT and the EDHB equipped cars were spaced appropriately from the locomotive north on the PTT.

Wheel chocks were installed on all four test cars to prevent car movements when the hand brakes were released during testing.

The test consist was moved to the test location. The cars in the test consist were uncoupled and positioned appropriately to simulate a long train. The track and vehicles were appropriately secured for protection and to prevent motion when the hand brakes were released.

The control console was positioned in the locomotive. To minimize test set up and teardown time, the control console was placed outside on the short nose of the locomotive which was facing the direction of the test cars. The antenna for the control console was magnetically mounted to the top of the cab of the locomotive, approximately above the position of the control stand. A truck mounted welder/generator unit was provided by TTCI and was used to supply power to the control console.

The long train test was performed following a previously approved test plan.

5. Wireless Control Test Results

This section describes the results from the EDHB wireless controls testing.

5.1 Short Train Test

From the control console, an operator successfully cycled the EDHB systems on each of the four cars in the test consist. Additionally, the control console correctly identified the current status of each of the hand brakes, both during operation and while the hand brakes were inactive.

The operator was also able to successfully cycle the EDHB systems of the entire consist from the control console with a single command. Hand brake status was correctly identified on the screens for each individual hand brake even when all brakes were actuated simultaneously.

The short train test results were nearly flawless. The only potential issue with the wireless communication during this test was a delay of up to a couple of minutes following power being applied to the system. During this period, devices are booting, and the mesh routing protocol is self-configuring by identifying neighboring nodes and establishing routing tables. While this does present a potential issue, no delays were observed that would be considered outside of normal system operating parameters. See Figure 8 for an example of application during the short train test.

Figure 8. EDHB on well car during in-lab wireless short train testing

5.2 Long Train Test

Initially the test subjects were placed approximately 200 feet between each test vehicle, for a total five vehicle consist length (i.e., not including the locomotive) of approximately 1,026 feet. From the control console, an operator was able to successfully cycle the EDHBs on each of the four cars in the test consist. Additionally, the control console correctly identified the current status of each of the hand brakes, both during operation and while the hand brakes were inactive.

The operator could also successfully cycle the EDHB systems of the entire consist from the control console with a single command. Hand brake status was correctly identified on the screens for each individual hand brake even when all brakes were actuated simultaneously.

While this test demonstrated full functionality, inconsistent communications occurred. Several times during testing, transmitted signals were not received by the receiving station. This issue was mitigated by retransmitting from the control station.

After the 200 ft. separation test, the test-consist was rearranged such that there were approximately 400 feet between each vehicle for a total consist length (i.e., not including the locomotive) of 1,737 feet. As with testing at the previous distances, this testing showed that the system functioned as expected, with an operator being able to apply and release each EDHB system individually, or on the entire consist simultaneously, wirelessly from the locomotive.

As observed while testing at the shorter distance, this test presented inconsistent communications. At times, multiple attempts were required before successful reception of the command was achieved. While all functionality was able to be validated, the communication inconsistency indicates that the system would not function acceptably on the commercial level. Figure 9 is a photo of one of the longer-train test setups.

Figure 9. Long train wireless test, 200 ft. test set up

6. Conclusion

From 2017 to 2019, FRA and SA's testing of the EDHB shows that the wireless communications addition to the system is feasible, but not reliable enough to provide the expected results for safety critical systems. The mesh network technology is intended to ensure reliable communications throughout a group of stations even if two stations cannot directly communicate with each other; this issue is supposed to be mitigated as long as each can communicate with other stations that can form a complete communications path between stations. While controls did operate as expected, communication between vehicles was sometimes unreliable, especially during the outdoor testing. When difficulties exist in communicating with neighboring stations, it becomes difficult to find a routable path to any station, rendering the mesh routing protocol less effective.

The signal strengths at the wireless stations that were observed during outdoor setup and testing were lower than anticipated. Previous testing during system development showed reliable communications between stations located 800 feet apart in an open outdoor setting; this was not achieved during this final testing. Until confirmed in future investigations and development, it is assumed that the rail vehicles themselves interfered with the signal propagation. This problem should be investigated and corrected so that the wireless component of the system can provide the intended benefits.

6.1 Recommendations

Currently, the wireless communications and control system is not yet commercially viable as problems were identified during research and testing.

It is recommended that further investigation and development into finding and correcting the causes of the unexpected communication and control interferences be undertaken.

It is anticipated that because the functionality of the wireless system was validated and worked appropriately, once the communications issues are potentially eliminated the wireless system will be commercially viable.

This work has taken the EDHB system even closer to railroad implementation; a viable option of wireless communications and control will enhance the attractiveness of the whole system for extensive railroad use and consequently a measurable increase in safety in operations.

7. References

1. Association of American Railroads. (2010). Hand Brakes, Manual of Standards and Recommended Practices S-475.

Abbreviations and Acronyms

ACRONYMS	EXPLANATION
Ah	Amp-hour(s)
AAR	Association of American Railroads
CFR	Code of Federal Regulations
VDC	Direct Current Volt(s)
ECP	Electronically Controlled Pneumatic
EDHB	Electrically Driven Set and Release Hand brake
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
GHBMEC	Geared Hand Brake Mechanical Engineering Committee
HMI	Human Machine Interface
I/O	Input/Output
IC	Integrated Circuit
k	Kilo
LED	Light-emitting Diode
MSRP	Manual of Standards and Recommended Practices
PSB	Passenger Services Building
PTT	Precision Test Track
ROB	Remote Operation Hand Brake
RFC	Request for Comments
SA	Sharma & Associates, Inc.
SLA	Sealed Lead-Acid
TTCI	Transportation Technology Center, Inc.
V	Volt(s)
W	Watt(s)
Wh	Watt-hour(s)